TEXTILE RESEARCH JOURNAL

VOLUME XXIV April, 1954 NUMBER 4

T. R. I. Annual Meeting

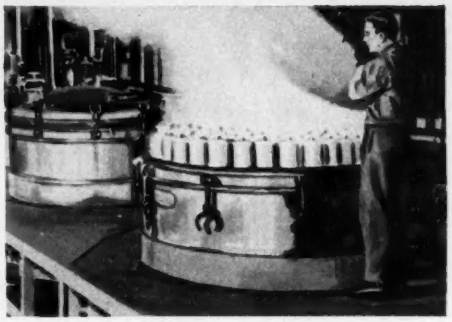
PUBLICATION OF

TEXTILE RESEARCH INSTITUTE

Editorial Office: 10 East 40th Street, New York 16, N. Y.

NOW FROM ROHM & HAAS
TRITON AS-35

A stable, high-foaming detergent, wetting agent, and level dyeing assistant



TRITON AS-35 is characterized by high foam, excellent detergency, and good wetting and level dyeing properties. TRITON AS-35 possesses excellent softening and lubricating properties for protecting fiber, yarn, or fabric during severe processing.

For kier boiling of cotton goods, TRITON AS-35 is mutually soluble and beneficial with pine oil, and gives fabrics improved absorbency and greater uniformity. Yet it shows no defects attributable to channelling or scum caused by hard-water soaps.

Its excellent detergency and high foaming properties make TRITON AS-35 extremely effective for soaping off prints.

For scouring piece goods, the cushioning effect of TRITON AS-35 suds minimizes wrinkling and creases.

Consider TRITON AS-35 as a level dyeing assistant for fast wetting in acid dyeing, uniform shades of good clarity with direct dyes, and increased dispersion and color value of acetate dyes.

Write today for complete information on TRITON AS-35

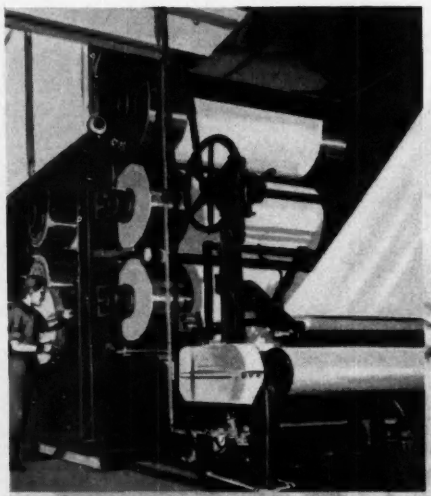
CHEMICALS FOR INDUSTRY

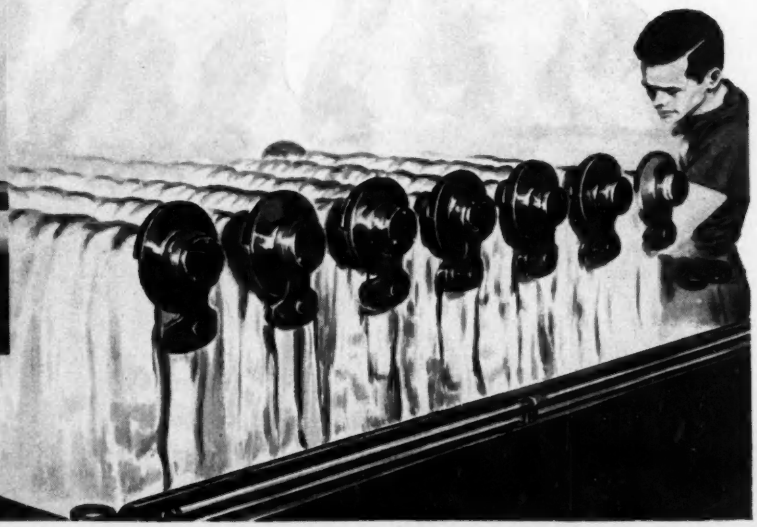
ROHM & HAAS COMPANY

WASHINGTON SQUARE, PHILADELPHIA 5, PA.

Representatives in principal foreign countries

TRITON *is a trademark, Reg. U.S. Pat. Off. and in principal foreign countries.*





TEXTILE RESEARCH JOURNAL

VOL. XXIV, No. 4 April, 1954

In This Issue

Solvent Etching of Cellulose Acetate Specimens for Electron Microscopy
Virgil Peck and Wilbur Kaye 295

Application of Electron Microscopy to the Study of Cellulose Acetate Fibers
Virgil Peck and Wilbur Kaye 300

Capacity, Dielectric Constant, and Power Factor of Fiber Assemblies
J. W. S. Hearle 307

Gordon Research Conference on Textiles 321

T. R. I. ANNUAL MEETING

The State of the Institute
J. H. Dillon 322

Results of Institute Research in 1953
James H. Wakelin 327

Ten Thousand and One Customer Complaints
Jules Labarthe 328

Some Chemical Experiments on Wools
Harold P. Lundgren 342

Optical and Electron Microscopic Studies of Cotton Fiber Structure
Mary L. Rollins and Verne W. Tripp 345

The Production and Properties of Solution-Dyed Acetate
Paul F. Flamm 357

The Complementary Nature of Fibers from Natural and from Synthetic Polymers
J. B. Quig and R. W. Dennison 361

Problems in Fiber Blends
J. B. Goldberg 374

Some Problems of Blending
Milton Harris 379

Finishing of Fabrics
Hector C. Borghetty 383

Progress in the Dyeing of the Newer Synthetic Fibers
Paul J. Choquette 387

Book Reviews 395

Editor: Julian S. Jacobs *Production Editor:* L. Joy Surgent

Associate Editors

H. J. Ball, Earl E. Berkley, Henry Eyring, W. J. Hamburger, Milton Harris, K. L. Hertel, H. Mark, E. R. Schwarz, Kyle Ward, Jr.

TEXTILE RESEARCH JOURNAL, published monthly at Prince and Lemon Streets, Lancaster, Pa., is devoted to the interest of research in textile and allied industries. It is published by Textile Research Institute.

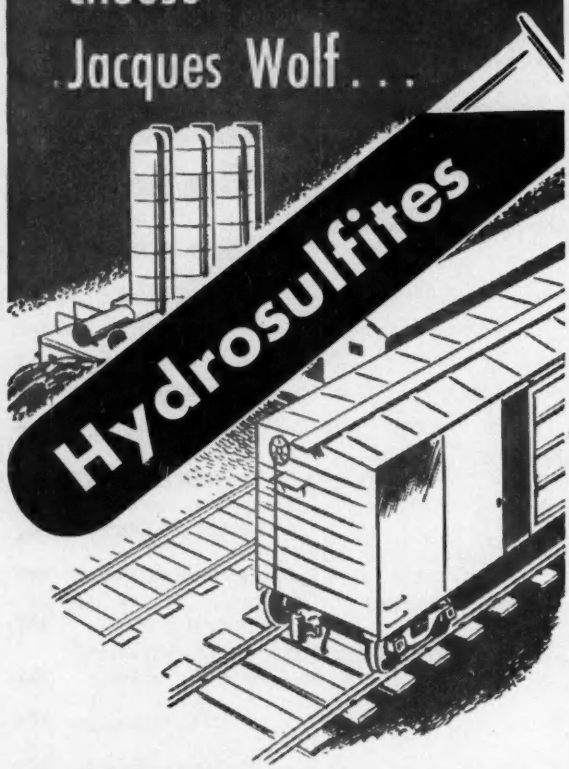
Entered as second-class matter, April 27, 1945, at the post office at Lancaster, Pa., under the Act of August 24, 1912. Accepted for mailing at special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized May 9, 1950.

Manuscripts and communications should be sent to the editorial office, 10 East 40th Street, New York 16, N. Y.

Subscription rates: $15.00 per year; additional for postage, 50 cents to Canada, $1.00 to all other countries. Single copies, $1.50 each.

Contents copyrighted 1954 by Textile Research Institute. Advertising rates supplied on request.

For test sample or carload quantities choose Jacques Wolf . . .



Jacques Wolf, Hydrosulfite specialists for approximately 40 years, offers a complete line of Hydrosulfites in different size crystals to meet specifications; various types adjusted to give you action where you want it, when you want it and how you want it.

TEST YOUR FREE SAMPLES OF THESE HYDROSULFITES

Hydrosulfite AWC ($NaHSO_2.CH_2O.2H_2O$.) for application and discharge printing.

Hydrosulfite of Soda Conc. ($Na_2S_2O_4$) a reducing agent for vat dyeing.

Hydrosulfite of Soda Q.D. ($Na_2S_2O_4$) for rapid dissolving for continuous vat dyeing.

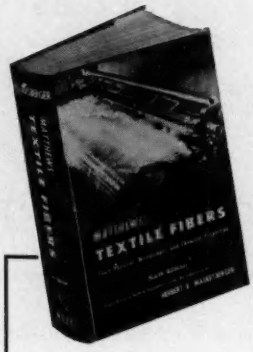
Hydrozin ($Zn(HSO_2.CH_2O)_2$) for stripping wool and acetate fibers and discharge printing of acetate dyed grounds.

Hydrosulfite BZ ($Zn(OH)HSO_2.CH_2O$) for stripping wool stock in an acid medium.

Write for Your Free Test Samples Today!

JACQUES WOLF & CO.
Chemicals PASSAIC, N.J.

Plants in: Clifton, N.J., Carlstadt, N.J., Los Angeles, Calif.



Just Out!

The New, Completely Revised 6th Edition of

MATTHEWS' TEXTILE FIBERS

Their Physical, Microscopic, and Chemical Properties

Edited by

HERBERT R. MAUERSBERGER

Director, Textile Dept., Fairleigh Dickinson College

COVERS ALL THE TEXTILE FIBERS— ANIMAL, PLANT, and MINERAL

Here is all the up-to-date data on every fiber used in the textile industry—including all the important new ones such as Dacron, Orlon, Dynel, Vicara, Acrilan, and X-51, as well as all the older synthetics like Nylon, regenerated rayon and the acetates.

Facts at Your Finger Tips

Comprehensive cross-indexing of this newly revised 6th edition makes for ease of reference. Each fiber is covered from the point of view of history, production and utilization. Included are chapters on identification methods and quantitative analyses, X-ray diagrams of natural and synthetic fibers, and fiber testing methods. 25 of the nation's leading experts and more than a dozen of the foremost producing and marketing organizations collaborated to make this the most complete and authoritative work yet published.

1954 1283 pages Illus. $16.50

MAIL FOR YOUR ON-APPROVAL COPY NOW

JOHN WILEY & SONS, Inc.
440 Fourth Avenue, New York 16, N. Y.

Please send me a copy of the new, completely revised 6th Edition of Matthews' TEXTILE FIBERS for FREE EXAMINATION. Within 10 days I will either return the book and owe you nothing or will send you $16.50 plus postage.

Name.....

Address.....

City.....Zone.....State.....

( ) SAVE POSTAGE. Check here if you ENCLOSE $16.50, in which case we pay postage. Same return privilege applies, of course.

(TRJ-44)

TEXTILE RESEARCH JOURNAL

VOL. XXIV, No. 4 APRIL, 1954

Solvent Etching of Cellulose Acetate Specimens for Electron Microscopy*

Virgil Peck and Wilbur Kaye

Research Laboratories, Tennessee Eastman Company, Division of Eastman Kodak Company, Kingsport, Tennessee

Abstract

A technique is presented for etching cellulose acetate fibers and films by direct solution of the surface molecules. A relatively undisturbed interior layer of polymer is uncovered for replication. Etching is achieved by immersing the polymer for a short period in acetone cooled to −50°C and then flooding with an excess of cold absolute alcohol. The resulting surfaces may be replicated for electron microscopy by any adaptable replica technique. Examples are given of the skin, orientation, voids, and pigment dispersions in cellulose acetate yarns.

Introduction

The application of the electron microscope to studies of the internal structure of plastics is of ever-increasing importance, since the high resolution of this microscope is very desirable in observing such structures as pigment dispersion, orientation, and crystallinity. Various workers have attempted to develop methods of observing these structures. In general, these methods fall into two classifications: (*1*) mechanical production of a very thin section of the original specimen for direct microscopic examination, and (*2*) removal of the outer surface material by chemical or physical means, followed by replication of the exposed inner surface. Each of the methods has its problems, and, to date, no real solutions to these problems have been obtained. It is the purpose of this paper to present a new technique for removing the surface material from cellulose acetate specimens, thereby exposing the relatively undisturbed underlying material for replication.

Two general approaches to the problem of removing surface material have been tried: (*1*) chemical and (*2*) physical. These are discussed below.

Chemical Removal

Chemical removal of material may be accomplished in at least three ways. The choice depends on the type of plastic to be treated.

Degradation by acids.—It is possible to change the chemical nature of surface molecules by means of acids and thus render the plastic soluble in some material which had previously been a nonsolvent. However, there is no published work on this technique for electron microscopy, and the authors have not been successful in using the degradation of cellulose acetate with acids as an etching procedure. But other plastics might be etched successfully in this manner if the proper acid could be found.

Degradation by ultraviolet radiation.—All plastics are subject to degradation by ultraviolet radiation, although to varying degrees. Degradation generally starts at the surface and proceeds slowly inward [5, 6]. Controlled exposure leaves a very thin layer

* Presented in part before the Electron Microscope Society of America, Philadelphia, Pa., November, 1951.

A paper which describes studies on abrasion and the skin effect on cellulose acetate fibers appears in this issue, p. 300.

of highly degraded polymer which might be removed to leave the underlying polymer exposed. This method at present appears to be limited by two factors: (*1*) the extremely long exposures necessary for degradation are undesirable in electron microscopy, and (*2*) in the case of cellulose acetate plastic, degraded material is removed only with difficulty and in extremely small sections.

Bombardment by ions.—Vacuum, or cathodic, etching of metals has received considerable impetus in the last few years, but little has been done to apply this same principle to the etching of plastics [2]. Two obvious difficulties for the average microscope laboratory to surmount are the production of the ion stream, since the plastic is an insulator, and the removal of the carbonaceous residue from the surface.

Physical Removal

Surface material may be physically removed from cellulose acetate in several ways. There are two general methods: (*1*) mechanical removal, and (*2*) etching by solvents.

Mechanical removal.—Many variations of this basic method have been tried. All of these necessitate the partial imbedding of the fiber or film in a matrix for handling and then using either a cutting edge or a very fine abrasive to remove the matrix and a portion of the specimen. The use of a cutting edge is very limited because a series of minute fractures is produced ahead of the cutting edge in the case of a hard or semihard plastic, and a smearing action is produced in the case of a rubbery or soft plastic. The use of an abrasive is undesirable because the particles of the abrasive are usually large compared to the structure to be observed. Thus, the application of mechanical means is limited, since the fine structure may be destroyed either by local heating and tearing or by imbedding of the abrasive particles.

Etching by solvents.—The method of direct solution of polymer molecules from the surface has as its goal the removal of material without mechanically disturbing the underlying molecules or leaving any degraded or extraneous deposits. The greatest difficulty in producing such an etch on plastics is that, in most solvents, plastics swell greatly before dissolving. However, by greatly reducing the temperature of the solvent, swelling can be kept to a minimum in the interior and localized to occur within the thin layer to be dissolved. This technique of etching by solvents is described below.

Experimental Techniques

Specimens of cellulose acetate films for etching were prepared in a conventional manner. Films were cast onto plate glass from a 5% solution of cellulose acetate (37% acetyl) in acetone. When dry, they were 0.005 ± 0.001 in. thick. To produce oriented amorphous films, the cast films were drafted at room temperature until they broke. The effect of heating cast films at 110°C for 24 hrs. was to produce unoriented amorphous films having no measurable increase in crystallinity. The latter effect has also been shown by Haas [1] and his coworkers to be true with ethylcellulose. X-ray patterns of each of the film types indicated the degree of orientation and crystallinity.

The fibers studied were of commercial cellulose acetate which had been given the usual draft during spinning.

The steps in etching cellulose acetate fibers or films follow.

Dissolving the Surface Polymer

Two 30-cc. beakers are supported in a wire frame in the upper portion of a Dewar flask. Acetone, cooled with Dry Ice to − 50°C, is added to the Dewar flask until the beakers are immersed nearly to the brims. About 5 cc. of dry acetone (or methyl ethyl ketone) is placed in the first beaker and allowed to cool to − 50°C. Then four or five clean, 4-den. cellulose acetate fibers about 1 in. long are scattered on the bottom of the second beaker and allowed to cool for several minutes. The acetone in the first beaker is then rapidly poured into the beaker containing the fibers. Slight agitation is desirable. Solution takes place very slowly, and in normal etching for electron microscopy no decrease in fiber diameter can be noted while observing the fibers in the solvent under a low-power microscope. However, if etching is continued for 5 to 10 min., the diameter decreases.

The etching of cellulose acetate films is carried out in the manner described, except that narrow strips of thin films are substituted for the fibers.

Although the time required to etch a sample depends upon its structure, 30 to 60 sec. is usually sufficient. Over-etching produces an extremely rough surface and makes replication difficult. It is neces-

sary to use a large volume of solvent in relation to the volume of cellulose acetate so that the dissolved molecules may form an extremely dilute solution and not precipitate when the action is stopped. Our experience has shown that water appears to have a detrimental effect upon control of the etching; therefore, it is necessary to use carefully dried solvents and to avoid as much condensation of moisture as possible during the procedure.

Stopping the Etching Action

The time required for desirable etching of a given sample must be determined by experiment. After the specimen has been in the solvent for the required time, the etching action is stopped without removal of the specimen. This is accomplished by the rapid addition to the solvent of a large excess of absolute ethyl alcohol (a nonsolvent) which has been previously cooled to at least − 50°C. A 5:1 ratio of alcohol to solvent is usually sufficient. At this stage, the specimen is removed with tweezers and transferred immediately to a beaker containing only absolute alcohol at room temperature. After the sample is washed, it is removed and dried in air. The surface is then ready for replication.

Any type of replica technique which is adaptable to the plastic specimen may be used to replicate the surface. However, the authors have found that the best results are obtained by use of direct specimen shadowing with uranium and supporting with an aluminum-beryllium alloy [3]. The composite replica may then be removed by dissolving the specimen or by using an evaporated hydrophilic stripping layer beneath the uranium shadows [4, 7]. In some cases, mechanical stripping may be used.

Discussion of Results

The technique described is limited to use on polymers for which there is a good solvent which can be cooled well below room temperature without solidifying. Although there are many such plastics, the work to date has been confined entirely to cellulose acetate containing an average of 2.3 acetyl groups per anhydroglucose unit.

Any pictures obtained should be interpreted with caution, since there is no published work showing actual photographs of the internal structure of cellulose acetate. Many experiments were performed to show that most of the structures observed are real, not artifacts. One immediately suspected source of artifacts is precipitate. However, the surfaces of films which were deliberately swollen in a suitable medium and then flushed with alcohol remained smooth. In another experiment, a fresh film was added to a solvent in which other films were being etched; then alcohol was added immediately. In this

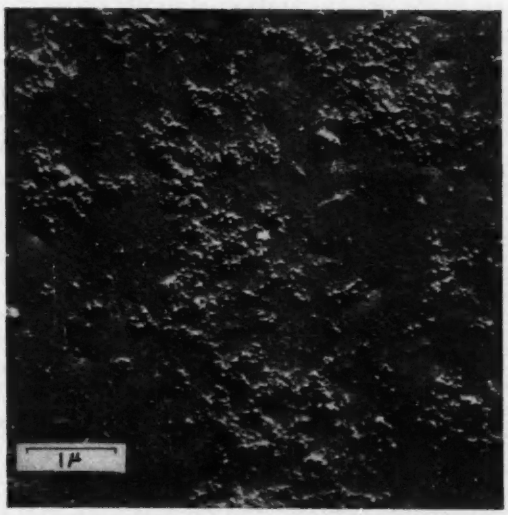


Fig. 1. *Typical surface appearance of a film of cellulose acetate cast on glass and etched lightly in methyl ethyl ketone.*

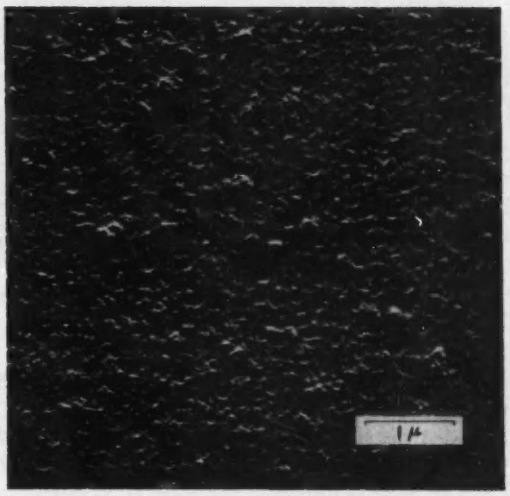


Fig. 2. *Same film as in Figure 1, but heated for 24 hrs. at 110°C before etching in methyl ethyl ketone.*

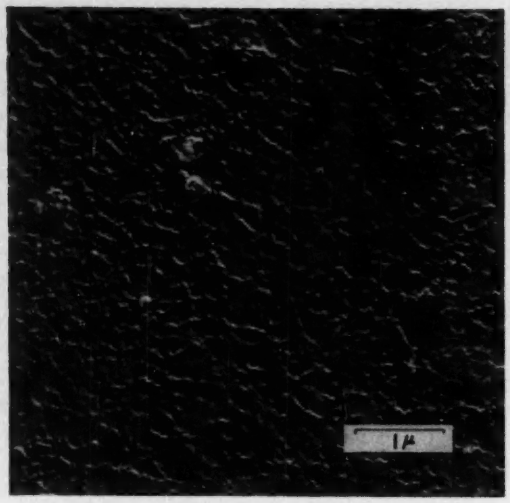


FIG. 3. *Surface replica of a bright cabinet-waste yarn etched in methyl ethyl ketone.*

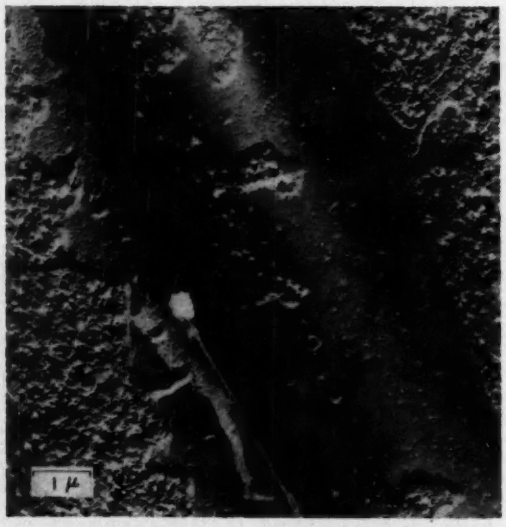


FIG. 4. *Replica from a production bright yarn after etching lightly with acetone (45 sec. at − 70°C).*

case no precipitate appeared on the surface of the fresh film; moreover, light-scattering measurements indicated that no precipitate was present in the solvent-alcohol mixture. It is possible to use higher alcohols, such as isopropyl and *n*-decyl, as quenching agents, and thereby obtain similarly etched surfaces. Fibers may even be dried in the etching solvent without being quenched by rapidly cooling the solvent to a temperature at which the rate of solution is negligible (approximately − 70°C) and holding at this reduced temperature in a vacuum chamber until evaporation of the solvent is complete. All of these methods produce similar surfaces, and this would not be true if precipitation occurred. Also, many unattacked regions on surfaces of lightly etched fibers contain no precipitated material.

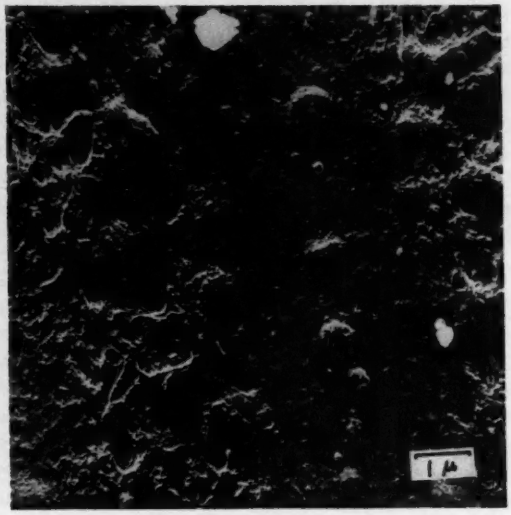


FIG. 5. *Production dull yarn etched deeply with methyl ethyl ketone.*

A typical photomicrograph of a film of cellulose acetate cast on glass and etched lightly in methyl ethyl ketone is shown in Figure 1. This surface before etching was quite smooth except for the minute molecular aggregation characteristic of this type of plastic, but etching disclosed many raised regions. This surface may be reproduced reasonably well using different batches of production-grade cellulose acetate.

If a second portion of the above film is heated for 24 hrs. at 110°C before etching under identical conditions, the resulting surface is composed of a mass of small, raised regions, as shown in Figure 2. Shorter heating periods produce results between those shown in the two photographs. Figure 3 shows the etched surface of a fiber from cabinet waste, a yarn spun into hot air but receiving no draft. The similarity between Figures 2 and 3 might be expected, since the cabinet waste is heated by the air. An interpretation of these pictures is not the

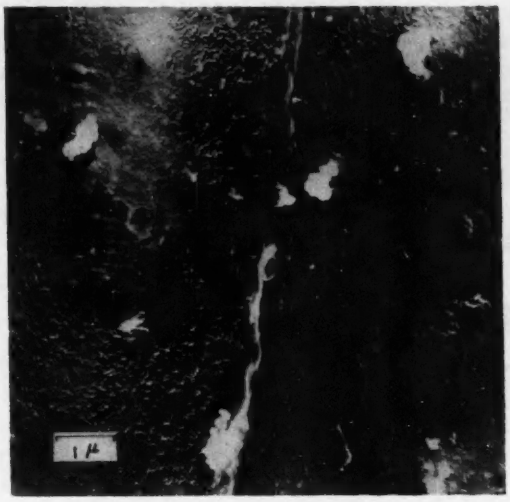


Fig. 6. *Dull yarn containing 0.5% TiO_2 etched lightly with methyl ethyl ketone.*

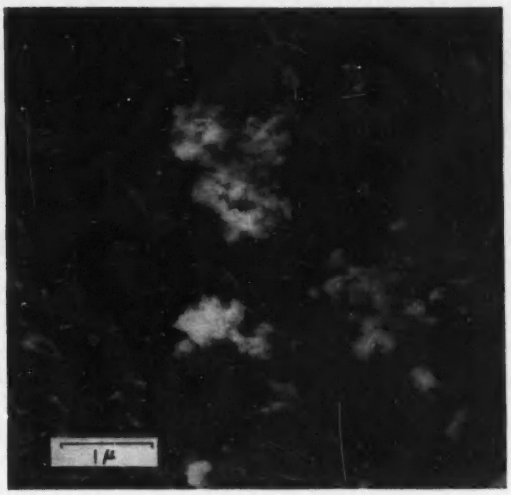


Fig. 7. *Red Chromspun yarn etched with acetone.*

purpose of this paper; rather, they are presented as examples of results obtainable with the technique.

Figure 4 shows the etched surface of an Estron fiber. The smooth region is believed to be a section of the skin which is less oriented by the draft than the skin on the outer portion of the convolution. The dark region is from within a cusp. Apparently, acetone evaporated more slowly from this particular section and allowed less draft to be absorbed; thus, less orientation of the skin resulted. This belief is substantiated by the fact that a film which has been oriented by drafting dissolves more rapidly in cold acetone than a nearly amorphous film. However, the effect of strains induced by drafting has not been studied, and strains may play a major role in this case. A discussion of the skin effect on cellulose acetate fibers is given in another paper (this issue, p. 300).

The existence of small voids within sections of cellulose acetate fibers has been suspected for some time. Figure 5 shows the etched surface of a production Estron fiber containing two bands representing the remains of two turbulent and spongy regions along the fiber axis. Although the voids have been entirely distorted by the solvent, the technique has proved most useful for discovering such banding beneath the skin. Vapor bubbles are also made apparent by this technique, although generally they are visible by ordinary optical means.

Pigment dispersion for coloring or delustering effects within a polymer is readily studied by the etching technique. Figure 6 shows the degree of dispersion of titanium dioxide in a cellulose acetate yarn delustered by 0.5% of this pigment. It will be noted that the aggregates have not been dispersed during the spinning operation. Pigments dispersed in fibers of Eastman Chromspun yarn are shown in Figure 7. Particle size and dispersion of the pigment are very important in controlling the color of the yarn.

Conclusion

The etching technique described is useful in studying some features of the internal structure of cellulose acetate fibers. Orientation of the molecules within the skin, existence of voids, insolubility of pigment particles, and foreign materials all cause a preferential etching of the surface. The variations in elevation produced are useful in electron microscopy. It leaves something to be desired as far as preferential attack within the interior of this plastic is concerned. However, efforts are being made to apply the method to other polymers which are believed to contain greater variations in such properties as crystallinity and orientation and which, therefore, might show greater solvent preference. Modifications of this technique will undoubtedly arise as new plastics are studied, since each plastic will present its individual problems.

Literature Cited

1. Haas, H. C., Farney, L., and Valle, C., Jr., *J. Colloid Sci.* **7**, 584 (1952).
2. Hillier, J., *J. Applied Phys.* **19**, 1191 (1948). (Abstract of paper presented at 1948 meeting of E.M.S.A., Toronto, Canada.)
3. Kaye, W., *J. Applied Phys.* **20**, 1209–14 (1949).
4. Kaye, W., *J. Applied Phys.* **20**, 1210 (1949).
5. Meyer, L. W. A., and Gearhart, W. M., *Ind. Eng. Chem.* **37**, 232 (1945).
6. Tichenor, R. L., *J. Polymer Sci.* **1**, 217 (1946).
7. Williams, R. C., and Backus, R. C., *J. Applied Phys.* **20**, 102 (1949).

(Manuscript received November 12, 1953.)

Application of Electron Microscopy to the Study of Cellulose Acetate Fibers*

Virgil Peck and Wilbur Kaye

Research Laboratories, Tennessee Eastman Company, Division of Eastman Kodak Company, Kingsport, Tennessee

Abstract

The application of electron microscopy to the study of cellulose acetate fibers has been demonstrated by the use of high-resolution Al-Be replicas. Abraded surfaces and the skin of fibers have been studied.

Various materials used for guides abrade the fiber surfaces in different manners. Ceramic guides cause a sticking action, whereas metallic guides produce a shearing of the cellulose acetate surfaces.

The skin consists of a highly oriented layer which is caused by drafting the fiber while solvent is still within the core. It is nonuniform and less extensible than the core. Other factors remaining constant, higher draft causes formation of a thicker skin, which is made up of layers. Yarns broken in tension show very jagged cracks and hairlike protuberances. Pigment dispersions and structural details are revealed by etching the fibers.

Introduction

The production of synthetic fibers in this country has developed into a tremendous industry, and the many varieties and types of artificial yarns have opened new fields of investigation. Research and quality control have worked together to give us many excellent synthetic yarns, but both must be continued, using every available tool.

The light microscope has been one of the indispensable tools of the textile research worker, and it should continue to be. However, in the electron microscope we have an additional tool which permits the high resolution and magnifications so often desired. To date in the textile industry nearly all emphasis has been placed on the old reliable light optics, and all too little emphasis on the new electron optics. This is understandable in view of the ease with which specimens can be prepared using light optics and the considerably greater difficulty of preparing specimens for electron microscopy. But certainly the information obtainable with the electron microscope should be added to that obtainable with the light microscope. It is the purpose of this article to present a portion of the data which we have obtained from a study of cellulose acetate fibers by the use of electron microscopy.

Since mechanical slicing of thin cross sections of fibers for electron transmission photomicrographs has not yet proved successful, it is necessary to use replicas of the fiber surfaces. We shall not describe the replica techniques here, because they have already been adequately described [1, 3]. However, we have been able to overcome the inherent shadowed structure of plastic replicas by direct shadowing of the fiber surfaces with uranium and using the Al-Be alloy backing layer, as developed by Kaye [2].

* Presented at the Fall meeting of The Fiber Society, Lowell, Mass., Sept. 10, 1953.

Thus, any shadowed fine structure observed is that of the original fiber, and not that of the molecular aggregate of a plastic replica. In this manner we have been able to obtain resolutions on the original surface of the order of 30 to 50 Å.

The information presented here is divided into two sections. The first of these deals with the study of fiber surfaces as they are found in production cellulose acetate yarns. The second section is concerned with an examination of the skin existing on the fibers.

Discussion

Fiber Surfaces

In considering electron microscopy, it is often assumed that the higher the magnification the more the information that can be obtained. However, because of the limited area which can be covered in an electron micrograph, such is usually not the case. High-magnification pictures of cellulose acetate fiber surfaces reveal small objects which probably are coiled molecules or aggregates of a few molecules [3]. Also, there are many large foreign objects usually attributed to incomplete removal of the lubricant. The amount of information in the high-magnification picture is limited; therefore, most of our work has been confined to magnifications of 30,000 × to 50,000 × on 8 in. × 10 in. prints.

Figure 1 shows two bands of irregularities often found on the surface of acetate fibers. The mechanism of formation of such bands along the fiber axis is not understood, but they may be due to turbulence at the spinneret jet. By proper control of spinning conditions, these regions can be kept at a minimum. Although they are not believed to be measurably detrimental to the physical properties of the fibers, there is some belief that they may affect the luster of a yarn if enough are present. The width of the bands varies from 0.5μ to 8–10μ, and the roughness increases with the width. However, there is one indication that these regions may not be entirely due to spinneret turbulence: the most severe cases of roughness are found in experimental acetate fibers which have been highly redrafted at temperatures just below the sticking point.

In studying the surfaces of fibers, one factor has been found predominant. This is the abrasion of the surfaces as they pass at high speed over various guides in the production machinery [8]. The photographs showing this abrasion were taken from lubricated fibers which had passed over guides at the rate of approximately 300 m./min.

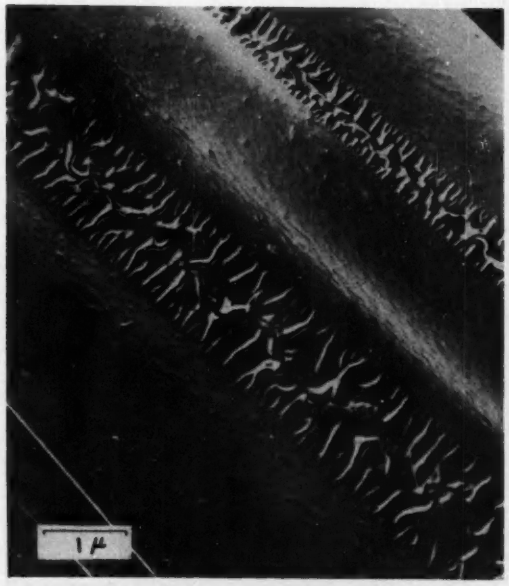


Fig. 1. *Surface irregularities on a production bright acetate fiber.*

Fig. 2. *Surface of an acetate fiber abraded by guides composed mainly of Al, Si, and Mg oxides.*

Figure 2 shows a drastic case of abrasion caused by running the yarns over polished guides made of a ceramic material composed mainly of Al, Si, and Mg oxides. This material is desirable from the standpoint of guide wear, but it causes undesirable abrasion of the the yarns. This is the type of abrasion which we have called "sticking." Evidently the acetate stuck to the guide material for a short time and a section of the acetate surface was actually torn from the fiber. This mass was shoved along the fiber for a short distance and then released. The action was repeated in rapid succession, producing a chattering effect along the abraded region. By using guides with a velvet finish instead of a high polish, it is possible to reduce the area in contact with the fiber and, to some extent, reduce the amount of abrasion. Use of conductive ceramics has no apparent effect upon the abrasion but does reduce the static charge on the yarn. This sticking type of abrasion can be explained by considering the high local temperatures which probably are attained at the contact surfaces. Because of the poor heat conductivity of ceramics, these temperatures might well be sufficient in local areas to reach the sticking point of the acetate.

It is common practice in production to use guides made of porcelain as well as the ceramic oxides mentioned. Figure 3 shows a surface abraded by passing the yarn over porcelain guides. The same type of abrasion is apparent, but the sticking appears to have been somewhat reduced. In this case the reduction is probably due to the fact that the porcelain guides were given a velvet finish. Similar finishes on porcelain and the ceramic oxides material give similar abrasion.

As an experiment, guides were made of polytetrafluoroethylene, and yarns were run over them. We expected a low coefficient of friction and, as a possible result, little abrasion. However, in only a few minutes the guides were completely notched from wear. Electron micrographs of the yarn surfaces revealed considerable abrasion with sticking. Although the roughness was not as severe as that caused by ceramic material, the surfaces were completely changed by the abrasion. Again, high local temperatures are believed to cause softening of both the acetate and the polytetrafluoroethylene. Also, it is well known that the latter plastic cold-flows rather easily. Although the coefficient of friction may have been initially low, it apparently at some time reached a high value locally.

Continuing with surface studies, let us now examine the effects of metallic guides. In this case we find an entirely different type of abrasion of the fibers.

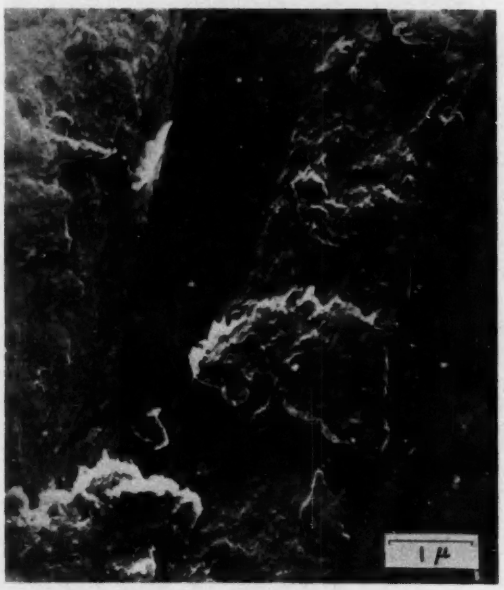


FIG. 3. *Surface of an acetate fiber abraded by porcelain guides.*

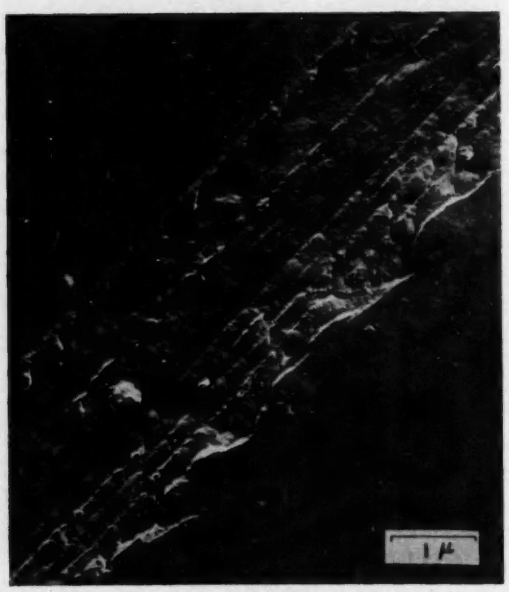


FIG. 4. *Surface of an acetate fiber abraded by steel guides.*

Figure 4 shows the result of passing the yarns over steel guides. Definite striations are visible, and little or no sticking is evident. We have called this "shearing" abrasion in view of the apparent cutting of acetate from the fiber surface. The material removed usually collects as dust around the guides. In this picture the lower portion of the abraded region shows a slight compression of the acetate ahead of the cutting edge, whereas at the upper edge of the abraded region the material has been literally ripped from the main body of the fiber. Such abraded regions differ considerably in depth, but they are seldom deeper than the one shown.

Figure 5 shows the surface of an acetate fiber after passing over stainless-steel guides. The same type of abrasion as shown in Figure 4 exists, but it is generally less severe. This correlates well with the fact that the measured coefficient of friction is less for acetate on stainless steel than on carbon steel with the same surface finish.

These data might lead one to believe that chromium-plated guides might be superior from the standpoint of yarn abrasion. Such proved to be the case, and yarns run over guides of bright, hard, chromium-plated brass showed very little abrasion. However, the measured coefficient of friction was contradictory to this, being little different from that for acetate on stainless steel. This discrepancy has not been explained.

Fiber Skin

Having observed some features of the surfaces of cellulose acetate fibers, let us continue with an examination of the outer layer, or skin.

The literature contains many articles presenting arguments both for and against the existence of a skin on this type of fiber. However, excellent work by Simmons and Howlett with the light microscope definitely showed cracking of the surface layer when tension was applied [7]. Studies of dichroism by Morey and Martin showed high orientation at the surface [5]. Chemical etching of the fibers revealed distinct differences in the outer layer [6]. Also, Morehead showed that minute projections were present on fibers which had been stretched 20% [4].

The mechanism of skin formation may be as fol-

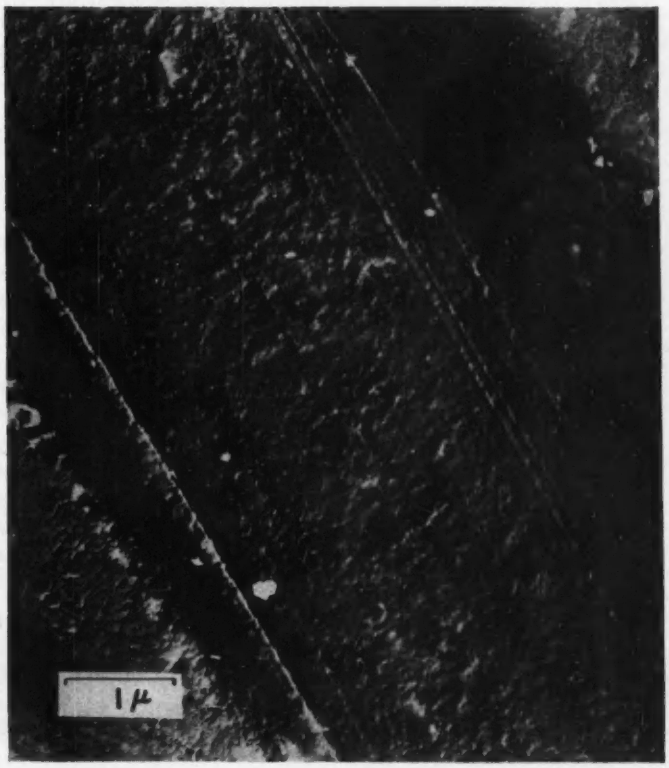


Fig. 5. *Surface of an acetate fiber abraded by stainless-steel guides.*

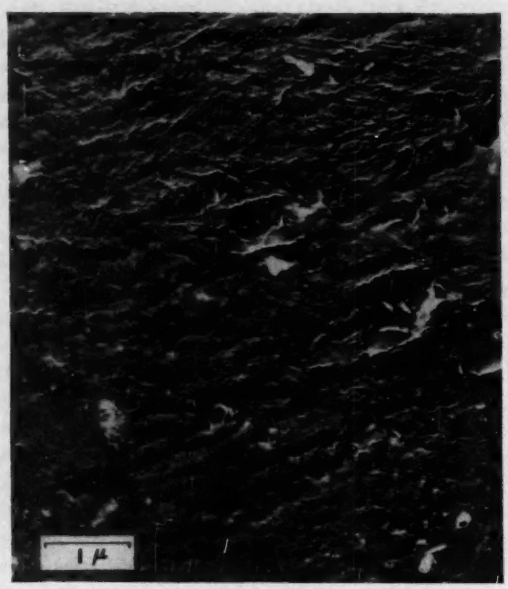


FIG. 6. *Undrafted acetate fiber stretched until a break occurred.*

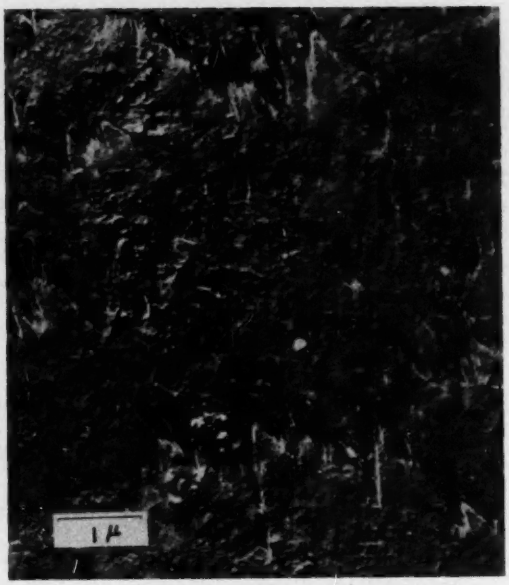


FIG. 7. *A production 4-den. bright acetate fiber broken in tension.*

lows: As the cellulose acetate solution is extruded into hot air, there is a sudden flash of acetone from the surface, leaving a thin layer of semiplastic material with a soft core. This outer layer must then support the entire fiber and absorb the draft given; in so doing, it is highly stretched and the chain molecules are oriented. The fluid core, however, is not sufficiently viscous to be highly oriented. The rate of acetone diffusion and evaporation becomes fairly uniform during the remainder of the process of fiber hardening. As acetone diffuses and evaporates, the core shrinks in diameter and pulls the skin layer about it. This shrinkage causes three to five convolutions to form along the fiber axis, thus producing a noncircular cross section.

Inasmuch as the fiber skin is believed to be caused primarily by drafting while the core is still fluid, one might expect that an undrafted fiber would have no skin. Electron micrographs of undrafted fibers reveal relatively smooth surfaces except for molecular aggregation and occasional extraneous material. There is little orientation and no cracking of a hard skin. The fibers are more nearly round and show fewer inverted cusps in cross sections than drafted yarns.

However, if an undrafted fiber is stretched until a break occurs, the surface changes and appears rough, as shown in Figure 6. Plastic flow and definite slippage of small sections has occurred. In many respects the slippage resembles that encountered in the slip bands of metals. However, there are no cracks resembling those in Figure 7, which shows the existence of a skin. Definite tapering has occurred in the fiber before breaking, and the broken ends do not show that a fracture has propagated sharply across the fiber. If a fiber is given a draft during spinning, as is done in production, several characteristics of the surface layer differ from those of this fiber.

In that portion of Figure 4 where the surface has not been abraded there is a typical example of the type of original surface found on all production, 4-den. fibers. There is molecular aggregation and evidence of orientation, and, on the whole, the fibers are rougher in fine detail than those of undrafted yarns.

The surface of a production, 4-den. fiber which has been broken in tension is shown in Figure 7. The area shown is approximately 1.5 mm. from the broken end. The surface layer has fractured, producing numerous ragged, transverse cracks 200–400 Å. deep. The V-angles formed along the cracks may prove to be of considerable interest as further studies are made. Only a single layer of material appears

FIG. 8. *An acetate fiber spun with high draft and cabinet temperature and then broken in tension.*

to have fractured, and plastic flow is evident in the depths of some cracks. The larger of these cracks have been observed many times with the light microscope. The hairiness, which Morehead and coworkers showed to exist on acetate yarn stretched 20%, is probably due to the projection of the small pieces of skin which have been torn out in the V-shape shown.

If the explanation which we have given for skin formation is correct, increasing the draft should produce a thicker skin if the cabinet temperature is kept high. That such is apparently the case is shown in Figure 8. This fiber was spun at a high cabinet temperature and with a high draft, and then broken in tension. The cracks show not only one, but several, layers of material which have fractured separately and progressively slipped to some extent. Each layer is approximately 200 Å. thick. We are not yet able to explain why the thicker skin should be layered instead of being uniform throughout its depth. Possibly a comparison may be made with injection-molded plastic specimens, in which a layered outer surface is frequently encountered.

Fibers spun with a high draft, but with the cabinet temperature reduced, emerged from the cabinet with the surface already fractured. The cracks were generally identical to those observed in Figure 7. Because of the slower rate of acetone evaporation and diffusion from the fiber, the core remained fluid longer; as a result, the thin skin initially formed near the jet had to absorb the high draft. This it could not do without cracking.

All of our work with cellulose acetate fibers to date indicates that the skin is thicker whenever the spinning conditions are such as to cause a high acetone content in the fiber interior during the initial elongation or draft. Therefore, one might assume that increasing the solids content and thereby reducing the acetone content in the dope would produce a fiber with thinner skin. To check the validity of the assumption, yarns were spun experimentally from high-solids dope and examined for the skin effect.

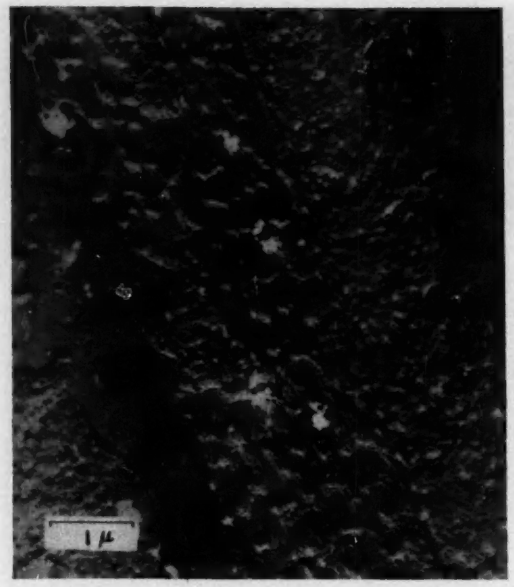


FIG. 9. *A production acetate fiber etched in cold acetone.*

It was found that the fibers were much more uniform in cross section and exhibited an almost indiscernible amount of cracking when broken in tension. Although a skin did exist, it was considerably thinner than on fibers in regular production yarns.

There are other indications of the fiber skin which are revealed by an etching technique using cold organic solvents [6]. Figure 9 shows the surface of an Estron fiber which has been etched in cold acetone. The smooth, raised regions are believed to be sections of the skin which have been attacked less rapidly by the acetone than the skin on the outer portion of the convolution. The dark region is from within a cusp. At present, we can only theorize as to differences within the skin. Possibly because of its close proximity to a cusp, this region lost acetone more slowly than the outer portion of the convolution and absorbed less draft; therefore, less orientation resulted. Also, this region may have been considerably less strained than the other portions of the skin. Although we do not know the effect of strain on rate of etching, we have found that thin films which have been oriented by drafting etch more rapidly in cold acetone than nearly unoriented amorphous films.

Nearly all of the electron micrographs of etched fibers which we have obtained reveal that the skin is usually very nonuniform over the fiber. Holes are etched through the skin in regions which one might expect to be continuous. However, there is always an over-all alignment with the fiber axis, as shown in Figure 9.

In addition to studying the skin, one can also reveal some of the features of the yarn interior by etching. The existence of turbulence voids, small bubbles, and pigment dispersions can be shown [6].

Summary

An examination of the surface of cellulose acetate fibers reveals the abrasive effects of various guide materials. At least two types of abrasion can be caused. Ceramic guide materials cause sticking, probably because of high local heating, whereas metals cause a shearing of the surface. From the data, it appears that metallic guides are superior to ceramic types from the standpoint of yarn abrasion.

The combination of draft and acetone evaporation during spinning appears to cause the formation of a surface layer 200–400 Å. thick. This layer may be described best as a skin which is highly oriented and less extensible than the core. It cracks when subjected to high tension, leaving hairlike protuberances. Layers may be formed in the skin under conditions of high draft and high cabinet temperatures if other factors remain constant. Pigment dispersions, voids, and nonuniformities in the skin are revealed in electron micrographs of etched fibers.

Electron microscopy has thus proved very useful in the study of some structural features of cellulose acetate fibers. By modifying existing techniques, similar studies may be made on other fibers, both natural and synthetic.

Literature Cited

1. Grube, W. L., and Rouge, S. R., *Am. Soc. Testing Materials, Proc.* **52**, 581–2 (1952).
2. Kaye, W., *J. Applied Phys.* **20**, 1209–14 (1949).
3. Kaye, W., *PSA Journal* **16B**, No. 8, 62–3 (1950).
4. Morehead, F. F., TEXTILE RESEARCH JOURNAL **22**, 379 (1952).
5. Morey, D. R., and Martin, E. V., TEXTILE RESEARCH JOURNAL **21**, 607–20 (1951).
6. Peck, V., and Kaye, W., TEXTILE RESEARCH JOURNAL **24**, 295 (1954) (this issue).
7. Simmons, S., and Howlett, F., *J. Textile Inst.* **40**, 590–604 (1949).
8. Takahashi, N., and Asaeda, T., *Bull. Inst. Text. France* **35**, 75–82 (1952).

(*Manuscript received December 30, 1953.*)

Capacity, Dielectric Constant, and Power Factor of Fiber Assemblies*

J. W. S. Hearle†

School of Textiles, Clemson College, Clemson, South Carolina

Abstract

The behavior of an air-fiber mixture is discussed. Measurements of the effective dielectric constant and power factor of yarns wound between cones have been made for a number of materials at various densities of packing, at frequencies between 50 c./sec. and 200 kc./sec., and at different moisture conditions. The results are discussed in their relation to the structure of the material, and are used to check the relation between electrical resistance and dielectric constant.

Introduction

The dielectric properties of textile fibers, or even of films of similar polymers, have been little investigated. They are of interest for various reasons. They influence capacity methods for measuring moisture and evenness. A greater knowledge of their behavior may lead to improved methods of measurement. In particular, when blends are being used it is desirable to know something about the properties of the component fibers, since a variation in blend may cause variations in capacity similar to those caused by variations in moisture content or mass.

There is evidence that the electrical resistance of fibers is closely related to their dielectric constant. The electrical resistance has various practical applications and is an important factor in determining the static charge remaining on fibers. There have also been suggestions of a direct effect of dielectric constant on the charge generated.

The dielectric properties determine the behavior of a material under high-frequency heating.

There is also a theoretical interest. Measurements of the variation of dielectric constant and power factor with frequency, moisture content, and temperature may give information about the structure of the material.

Stoops [32] measured the dielectric constant of dry cellulose film at various frequencies and temperatures. An immersion method was used by Errera and Sack [10] to measure the dielectric constant of dry fibers, and by de Luca *et al.* [8] for dry cellulose. Argue and Maass [1] investigated purified cotton cellulose; New [21] measured the capacity and power factor of cotton at an arbitrary degree of packing; and Balls [4] tested raw cotton at 1.755 Mc./sec. King [15, 16] measured the dielectric constant of keratin and nylon films; and Shaw and Windle [27, 28] measured the dielectric constant of wool, mohair, nylon, and cellophane at microwave frequencies. Wood at high frequencies was tested by Skaar [26], and by Witkopf and Macdonald [35], and leather by Weir [34]. Some of the less hygroscopic polymers of which fibers are made have been investigated more extensively in the solid form, notably Terylene by Reddish [25], and the polyesters and polyamides by Baker and Yager [2, 3].

In the present investigation, the dielectric constant and power factor of yarns wound on cones have been measured at various frequencies and moisture contents.

Air-Fiber Mixtures

A difficulty in measuring the dielectric properties of fibers is the problem of relating the properties of the air-fiber mixture being tested to the properties of the fibers themselves. Various formulas have been used, but they are all approximations, and it is difficult to see how closely they should fit particular experimental conditions. Some of these formulas will now be reviewed. We define ϵ as the dielectric constant of the fiber material (assumed uniform), ϵ_m as the effective dielectric constant of the mixture (*i.e.*, the ratio of capacities, with and without the material present), and P as the volume fraction of fiber between the plates of the condenser.

* Presented at a meeting of The Fiber Society in Lowell, Mass., Sept. 10, 1953.

† On leave of absence from Department of Textile Industries, College of Technology, Manchester, England.

(*i*) If the material is assumed to occupy only a fraction of the total area, but to be continuous between the plates (Figure 1(*a*)), and assuming there is no distortion of the field, we have

$$\epsilon_m = 1 + (\epsilon - 1)P. \tag{1}$$

The line *A* in Figure 1 is ϵ_m plotted against *P* for $\epsilon = 10$.

Balls [4] used this formula for fibers lined up perpendicular to the plates; but, under these conditions, the distortion of the electric field cannot be neglected. Due to the high surface/volume ratio in fibers, there will be a large edge effect. The lines of force will concentrate in the region of high dielectric constant, increasing the capacity above its expected value. A curve such as *B* in Figure 1 will be obtained.

(*ii*) If the material is assumed to occupy the whole area, but only a fraction of the distance between the plates (Figure 1(*c*)), we have

$$\epsilon_m = \frac{1}{\frac{P}{\epsilon} + (1 - P)}. \tag{2}$$

This gives curve *C* (Figure 1).

(*iii*) A combination of the above two cases, with α as the fraction of area occupied and β as the fraction of the distance between the plates (Figure 1 (*d*)), gives

$$\epsilon_m = \frac{\alpha}{(1 - \beta) + \frac{\beta}{\epsilon}} + (1 - \alpha). \tag{3}$$

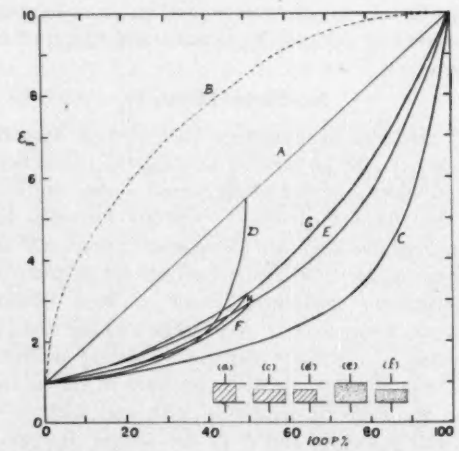


FIG. 1. *Theoretical curves for mixtures.*

Most interesting is the case when α is a constant. We then have

$$\epsilon_m = \frac{\alpha^2}{\alpha - P + \frac{P}{\epsilon}} + (1 - \alpha). \tag{4}$$

This is drawn in Figure 1 as curve *D* for $\alpha = 0.5$.

(*iv*) If molar polarizations are additive, the following equation holds [5]:

$$\frac{\epsilon_m - 1}{\epsilon_m + 2} = P\frac{\epsilon - 1}{\epsilon + 2}. \tag{5}$$

This gives curve *E* (Figure 1).

It is not valid for large particles, due to the failure of the assumption, on which it is based, that the Lorentz internal field holds at all places. It has been shown to be a good approximation for small values of *P* [24].

Various improvements on this formula for particular conditions have been suggested [6, 23, 31, 33].

If ϵ is very nearly equal to 1, so that the difference between $\epsilon_m + 2$ and $\epsilon + 2$ is negligible, equation (5) reduces to

$$\epsilon_m - 1 = P(\epsilon - 1), \tag{6}$$

which is the same as equation (1).

This is valid for a mixture of gases, and Balls [4] adopted it for fibers arranged parallel to the plates. However, neither the assumption that $\epsilon \doteq 1$ nor the original assumption on which equation (5) is based is justified here.

(*v*) A combination of cases (*ii*) and (*iv*), illustrated in Figure 1(*f*), would give curve *F* of Figure 1.

(*vi*) Lichtenecker [18] proposed a logarithmic relation, which for a mixture in which one component has unit dielectric constant reduces to

$$\log \epsilon_m = P \log \epsilon. \tag{7}$$

This has been applied, with experimental support, by Shaw and Windle [27] to the transverse dielectric constant of fibers wound solenoidally. The curve obtained is drawn as curve *G* in Figure 1.

(*vii*) A combination of cases (*ii*) and (*vi*) gives curve *H* of Figure 1.

Experimental

Measurement of Capacity and Power Factor

A General Radio Company Capacitance Bridge, type 716-C, was used. This is a Schering bridge

with a frequency range of 30 c./sec. to 300 kc./sec. A block diagram of the circuit is shown in Figure 2. The signal source was an audio-oscillator, and the detector was a cathode ray oscillograph. The substitution method was used in the bridge: the auxiliary variable condenser was first adjusted so that the bridge balanced with the internal standard condenser at a selected value; and the changes in the setting of the internal standard condenser and the dissipation factor dial, when the test condenser was connected, were noted. Due to the high dissipation factors, it was necessary, in almost all cases, to use the full, unapproximated expressions for the calculation of the unknown capacity and dissipation factor.

In a few tests, at the low frequencies, when the capacity or dissipation factor was beyond the range of the bridge, an additional condenser was connected in series with the test condenser in order to make the measurements.

The Test Condenser

The test condensers were made up of two aluminum cones (Figure 3). A layer of yarn, about 2 mm. thick, was wound on the inner cone under a tension of 120 g. weight, the turns of yarn being close together. For measurements at laboratory conditions, the cone was then left exposed for at least 24 hrs. Then the outer cone was pressed on; and the two leads were connected to the bridge for the measurement. For other conditions, the cone was placed in a desiccator over an appropriate salt solution. To make a test, the cone was removed from the desiccator, the outer cone was pressed on, the cones and yarn were weighed (for determination of moisture content), and then the electrical measurements were carried out. Preliminary experiments showed that no detectable change in dielectric constant or power factor occurred during this procedure.

When a very high pressure was used to press on the outer cone, there was some decrease of capacity with time. This was independent of whether the electrical field was connected or not, so that it was probably due to some internal rearrangement of the fibers between the cones. Under the conditions of the experiments, the error due to this effect could be neglected.

The capacity between the cones with air as the dielectric was obtained from the position of the outer cone relative to the inner one, a previous calibration having been made with the two cones separated only by small spacers of polystyrene. A theoretical calculation gave values for the air capacitance in good agreement with the experimental values.

Since the yarn extends beyond the outer cone, the only edge effect will be due to the slight difference in the distribution of the electric field when the material is present. We may assume approximately that the edge capacitance is equivalent to that caused by an additional length of outer cone equal to half the distance between the plates. This additional area would be about 4% of the total area of the outer cone. The change in capacitance due to the change of field distribution would not be expected to be more than 10% of the total edge capacitance. Therefore, the error due to edge effect should not be greater than 0.5%.

The density of packing of the material is given by the relation

$$P = \frac{\text{volume of material}}{\text{over-all volume occupied}}.$$

The volume of material was obtained from the mass divided by the density; and the over-all volume

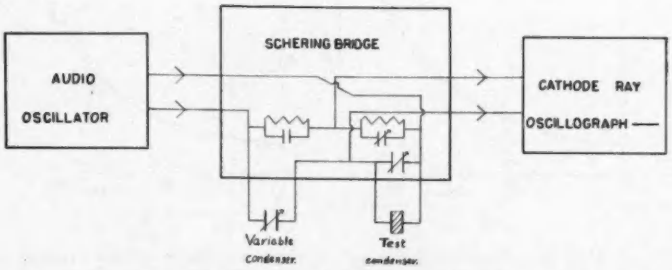


FIG. 2. *Block diagram of circuit.*

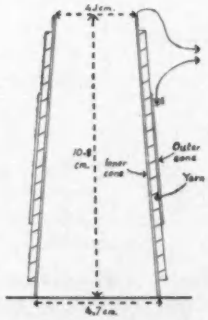


FIG. 3. *Cone condenser.*

occupied from the dimensions of the cones and the position of the outer cone. With staple fiber yarns, values of P of about 0.5 were obtained, but continuous-filament yarns gave much higher values, approaching the theoretical maximum, which is 0.91 for hexagonal close-packing of circular fibers.

This arrangement of yarn between cones means that the transverse properties of the fibers will be dominant, although, particularly with staple fibers, some parts of the fiber may be parallel to the field.

Materials Tested

The following materials were used in the experiments:

cotton—American, 12s yarn
viscose rayon staple—12s, 2½-in. staple, 5 den.
viscose rayon continuous filament—150 den., 40 filament, bright (for the results given in Figure 6(*b*) 300 den. was used)
acetate rayon staple—12s, 4 in., 5.5 den.
acetate rayon continuous filament—150 den., 40 filament, dull
wool—woolen spun yarn
nylon staple yarn
nylon continuous filament—260-den. tire cord
Orlon staple—30s/2 yarn
* Saran continuous filament—S548
* Fiberglas continuous filament, 150-1/0, heat-cleaned
* Acrilan staple—20s, 3 den., 2 in.
* Vinyon staple—20s, 3.2 den., 2 in., bright
* Ardil staple—28s, 5 den., 5 in., dry-spun

For most of the tests, the materials were used as received. Some of the specimens were also tested after they had been extracted in a Soxhlet apparatus with methanol and benzene, to remove surface finish.

Expression of Results

A condenser with an imperfect dielectric can be described in various ways. In this paper it is expressed in terms of the equivalent parallel capacity, C_p, and resistance, R_p (Figure 4). Other quantities are then defined as follows: dissipation factor or loss tangent $= D = \tan \delta = 1/2\pi f C_p R_p$, where f = frequency in cycles/sec. and δ = loss angle; power factor $= \cos \phi = D/\sqrt{1+D^2}$, where $\phi = \pi/2 - \delta$ = phase angle; dielectric constant $= \epsilon = C_p/C_o$, where C_o = capacity of condenser with air dielectric.

Whenever an air-fiber mixture is referred to, the effective dielectric constant of the mixture is denoted by ϵ_m.

The above quantities may be related to the complex dielectric constant, $\underline{\epsilon}$:

$$\underline{\epsilon} = \epsilon' - j\epsilon''.$$

It can be shown that: real part of dielectric constant $= \epsilon' = \epsilon$; loss factor $= \epsilon'' = 1/2\pi f C_o R_p$; and $\tan \delta = \epsilon''/\epsilon'$. The vector diagrams in Figure 4 illustrate these relations.

* The author wishes to express his thanks to the following companies for supplying samples for use in this work: Dow Chemical Co. (Saran); Owens-Corning Fiberglas Corp. (Fiberglas); American Viscose Corp. (Acrilan and Vinyon); Imperial Chemical Industries (New York) Ltd. (Ardil).

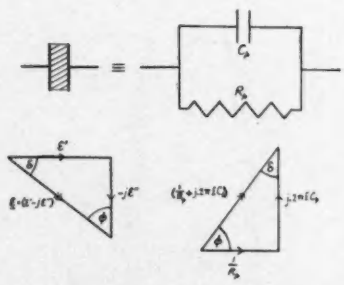


FIG. 4. *Imperfect condenser and equivalent parallel circuit, with corresponding vector diagrams.*

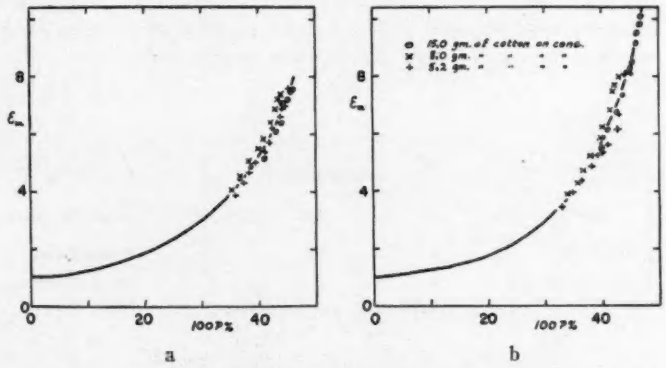


FIG. 5. *Reproducibility of results.* a—*Three similar cotton specimens; 65% R.H., 70°F, 1 kc./sec.* b—*Three thicknesses of cotton on cone; 65% R.H., 70°F, 1 kc./sec.*

Results

Reproducibility

Figure 5(*a*), which shows measurements made on similar specimens of cotton on three cones, shows that a consistent value is obtained for the dielectric constant of the mixture. Figure 5(*b*) shows that the thickness of the layer of yarn on the cone has little effect on the results obtained.

Effect of Density of Packing

In Figure 6 the dielectric constant is plotted against the percentage of the volume occupied by fiber. In each set of points, the value of P is varied by varying the pressure used in pushing on the outer cone. The results on viscose rayon suggest that this gives curves similar to curve F of Figure 1. This means that, as the outer cone is pressed on, it is mainly effective in altering the surface layers and has little effect on the density deeper in the wound yarn. However, applying the equation for curve F does not give a good quantitative fit, and leads to absurdly high values for the dielectric constant of the fiber. The Lichtenecker equation (for curve H of Figure 1) gives more reasonable results, but these are probably still too high. The use of equation (4) (*i.e.*, a linear extrapolation through the point of maximum density (curve D, Figure 1)) would be expected to give too low a value. This is confirmed by comparison of the results in Tables II and III. It thus appears that none of the models suggested could be used to give a reliable value for the absolute dielectric constant of the fiber.

Effect of Frequency

Figures 7 and 9–19 show the variation of dielectric constant and power factor of cotton, viscose rayon,

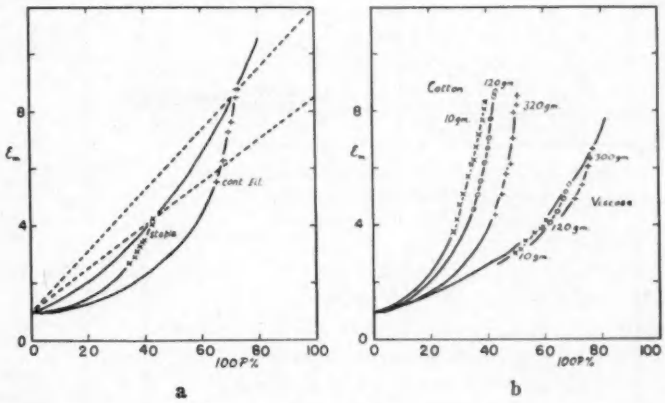


Fig. 6. *Effect of density of packing.* a—*Viscose rayon; 65% R.H., 70°F, 1 kc./sec.* b—*Cotton; 65% R.H., 70°F, 1 kc./sec. Viscose rayon continuous filament; 45% R.H., 70°F, 1 kc./sec.*

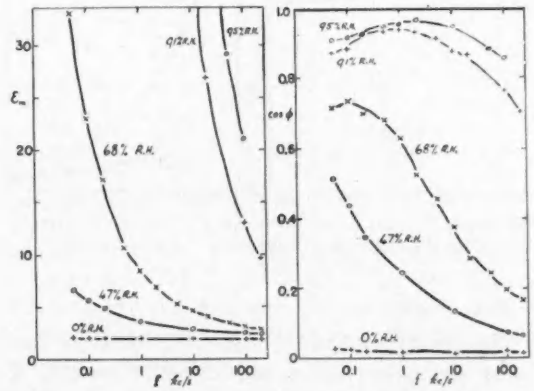


Fig. 7. *Effect of frequency. Cotton; 70°F, 100P ≏ 44%.*

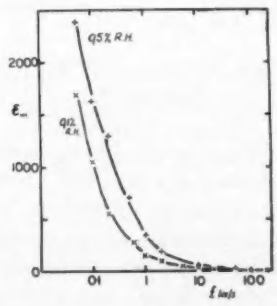


Fig. 8. *Effect of frequency. Damper cotton, 70°F, 100P ≏ 49%.*

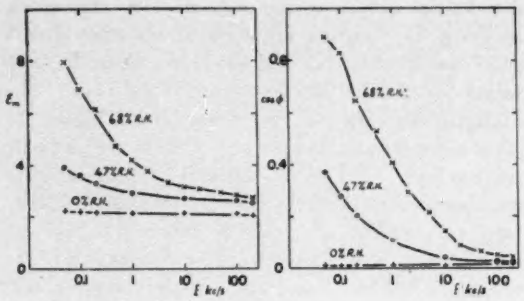


FIG. 9. *Effect of frequency. Viscose rayon staple; 70°F, 100P ≏ 43%.*

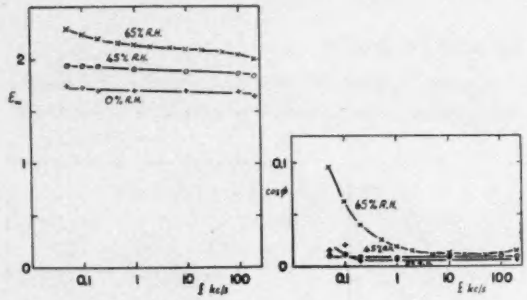


FIG. 10. *Effect of frequency. Acetate rayon staple; 70°F, 100P ≏ 45%.*

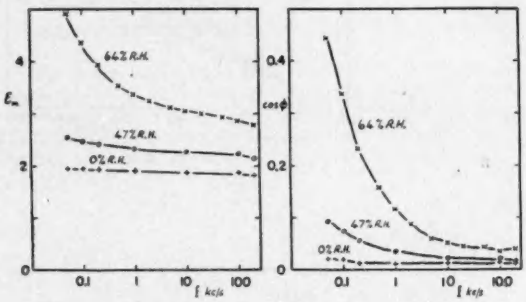


FIG. 11. *Effect of frequency. Wool; 70°F, 100P ≏ 52%.*

acetate rayon, wool, nylon, Orlon, Acrilan, Vinyon, Ardil, and extracted Dacron staple fibers and Saran and Fiberglas continuous filaments at three humidities. The percentages of volume occupied by fiber in these air-fiber assemblies are between 38% and 53% for the staple fibers; and between 63% and 70% for the continuous filaments. The very high values obtained for cotton at higher humidities are shown in Figures 7 and 8.

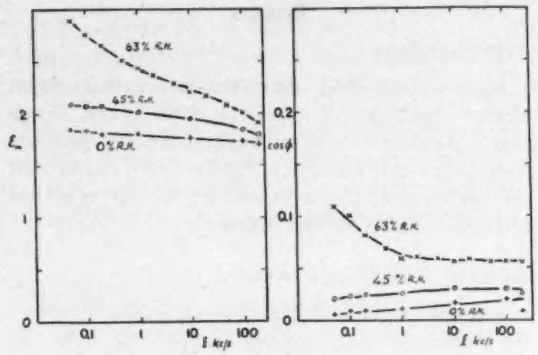


FIG. 12. *Effect of frequency. Nylon staple; 70°F, 100P ≏ 53%.*

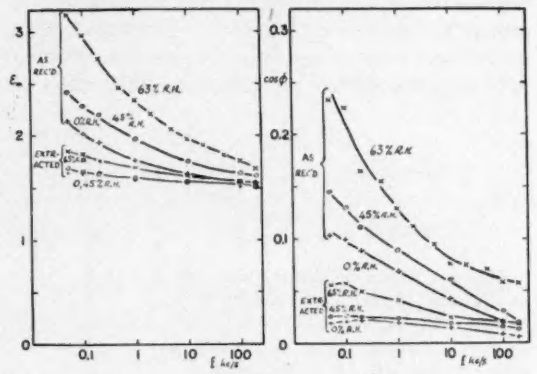


FIG. 13. *Effect of frequency. Orlon staple; 70°F, 100P ≏ 42%.*

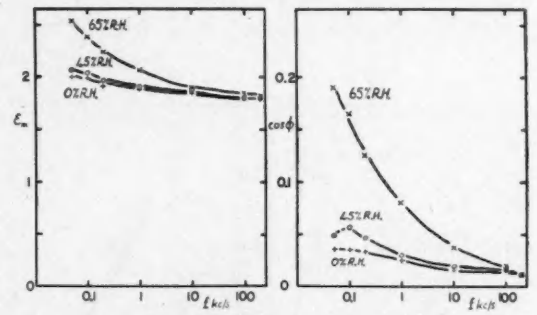


FIG. 14. *Effect of frequency. Acrilan staple; 70°F, 100P ≏ 54%.*

Effect of Moisture

Figures 20–25 show the variation of dielectric constant and power factor with moisture content, M (expressed as a percentage of the weight of undried material), for the more hygroscopic staple fibers at 1 kc./sec. and 100 kc./sec.

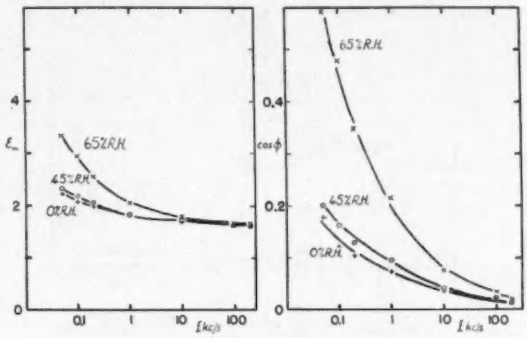


FIG. 15. *Effect of frequency. Vinyon staple; 70°F, 100P ≏ 46%.*

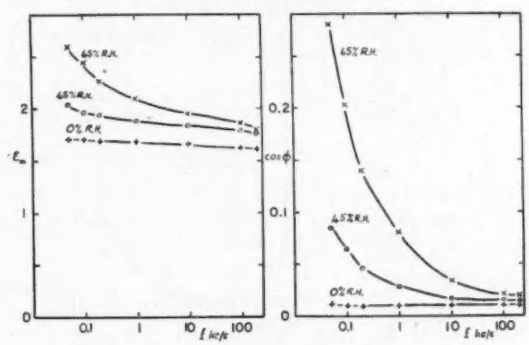


FIG. 16. *Effect of frequency. Ardil staple; 70°F, 100P ≏ 39%.*

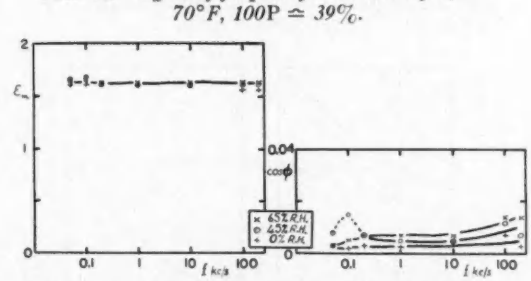


FIG. 17. *Effect of frequency. Extracted Dacron staple; 70°F, 100P ≏ 48%.*

Of the nonabsorbing fibers, Saran (Figure 18) and Dacron (Figure 17) showed no variation in dielectric constant, and only a small change in power factor between 0% R.H. and 65% R.H.; but Vinyon (Figure 15) and Fiberglas (Figure 19) showed a marked change at low frequencies, presumably due to some surface effects.

Effect of Cleaning

Table I gives a comparison of the values obtained for specimens as received with those for extracted

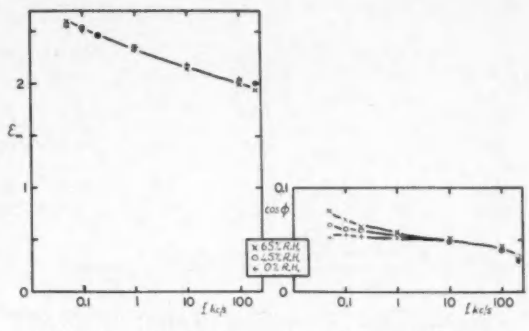


FIG. 18. *Effect of frequency. Saran continuous filament; 70°F, 100P ≏ 70%.*

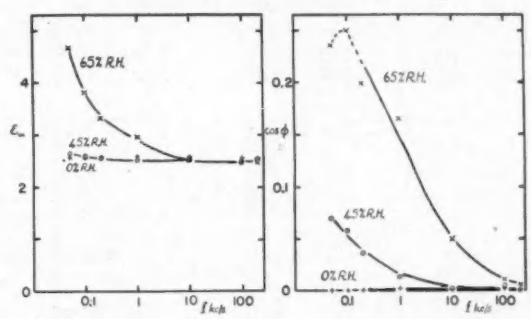


FIG. 19. *Effect of frequency. Fiberglas continuous filament; 70°F, 100P ≏ 63%.*

specimens. A linear extrapolation was used to bring them to the same value of P; this is only an approximation, and where, as in Vinyon, the difference in the values of P is large, may introduce appreciable error. It may be seen that the nylon, Acrilan, and Vinyon specimens were little affected. Lower values of dielectric constant and power factor were shown by the extracted specimens of wool, Orlon, and, to a much greater extent, Dacron.

Comparison of Different Materials

Figure 26 shows the dielectric constant of the air-fiber mixture for different materials at 65% R.H., 70°F, and 1 kc./sec., plotted against density of packing.

To obtain the series of comparative values of dielectric constant given in Table II, a linear extrapolation from $\epsilon = 1$ at $P = 0$ to $P = 1$ was made through the point of maximum density. It should be noted that, as shown above, these values would be expected to be lower than the true values of the dielectric constant of the fiber, and that the continuous-filament

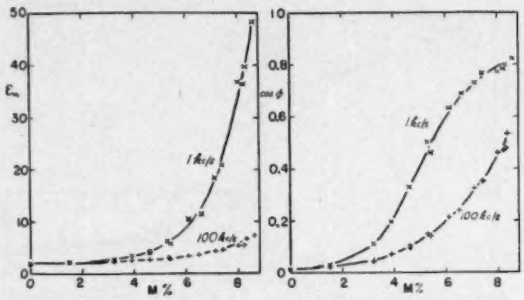


FIG. 20. *Effect of moisture. Cotton; 70°F, 100P ≃ 47%. At higher moisture contents the following values were obtained:*

	1 kc./sec.		*100 kc./sec.*	
M(%)	ϵ	*cos φ*	ϵ	*cos φ*
11.8	*155*	*.942*	*13.0*	*.768*
12.7	*347*	*.955*	*21.0*	*.861*

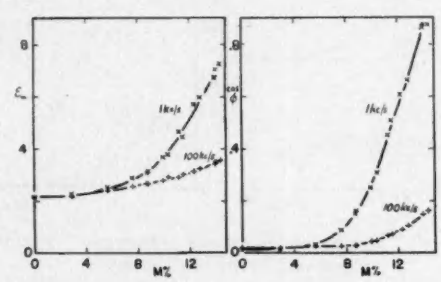


FIG. 21. *Effect of moisture. Viscose rayon staple; 70°F, 100P ≃ 45%.*

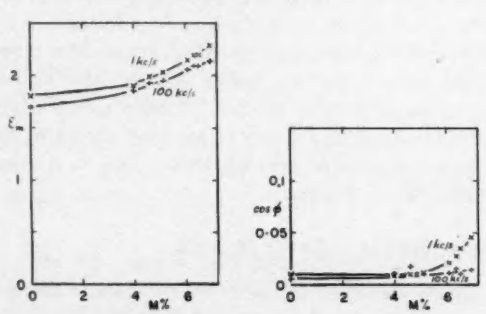


FIG. 22. *Effect of moisture. Acetate rayon staple; 70°F, 100P ≃ 46%.*

yarns which give a greater density of packing give a higher extrapolated value.

Table III lists other values of dielectric constant given in the literature. As expected, where they can be compared they give higher values, but the general behavior is similar. In Table IV are values of the

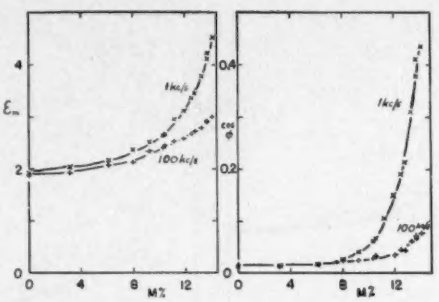


FIG. 23. *Effect of moisture. Wool; 70°F, 100P ≃ 52%.*

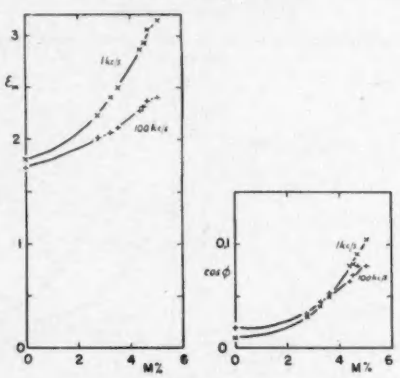


FIG. 24. *Effect of moisture. Nylon staple; 70°F, 100P ≃ 61%.*

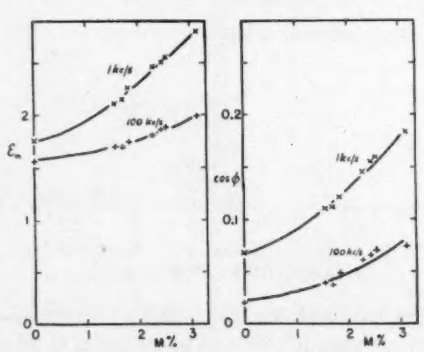


FIG. 25. *Effect of moisture. Orlon staple; 70°F, 100P ≃ 42%.*

squares of refractive indices which equal the dielectric constant at optical frequencies (10^{15} c./sec.).

Figure 27 gives curves of power factor plotted against density of packing at 65% R.H., 70°F, and 1 kc./sec.

TABLE I. Comparison of Extracted and Unextracted Specimens

Materials	R.H. (%)	100 P% experimental	100 P% corrected	Values of ϵ_m at: 100 c./sec.	1 kc./sec.	10 kc./sec.	100 kc./sec.	Values of cos ϕ at: 100 c./sec.	1 kc./sec.	10 kc./sec.	100 kc./sec.
Wool, unextracted	65	55.9	50	4.00	3.13	2.84	2.67	.321	.106	.047	.032
extracted	65	39.8	50	2.81	2.48	2.33	2.27	.195	.083	.038	.029
Nylon, unextracted	65	53.9	50	2.63	2.34	2.12	2.00	.094	.054	.052	.052
extracted	65	47.4	50	2.62	2.43	2.23	2.01	.072	.063	.064	.065
Orlon, unextracted	65	41.8	40	2.88	2.28	1.93	1.73	.215	.123	.073	.056
extracted	65	37.8	40	1.88	1.73	1.66	1.60	.061	.044	.027	.022
Orlon, unextracted	45	41.6	40	2.23	1.93	1.72	1.62	.125	.086	.059	.030
extracted	45	39.0	40	1.69	1.62	1.57	1.55	.028	.025	.019	.016
Orlon, unextracted	0	41.3	40	1.99	1.75	1.62	1.55	.096	.067	.062	.020
extracted	0	39.1	40	1.66	1.59	1.57	1.53	.023	.020	.015	.009
Acrilan, unextracted	65	53.7	50	2.28	2.00	1.86	1.80	.154	.076	.035	.019
extracted	65	48.1	50	2.08	1.94	1.84	1.75	.048	.043	.037	.033
Dacron, unextracted	65	53.7	50	—	39.4	—	—	—	.773	—	—
extracted	65	47.5	50	—	1.66	—	—	—	.007	—	—
Vinyon, unextracted	65	45.4	35	2.51	1.82	1.62	1.52	.419	.168	.059	.029
extracted	65	26.3	35	2.34	1.82	1.53	1.48	.201	.176	.051	.013

TABLE II. Extrapolated Values of ϵ

100 P%*	R.H. (%)	M (%)	100 c./sec.	1 kc./sec.	10 kc./sec.	100 kc./sec.
			Cotton			
43.3	0	0	3.3	3.2	3.1	3.0
44.5	45	5	11.7	7.1	5.3	4.4
45.4	65	6.5	51	18	9.4	6.0
			Viscose staple			
43.7	0	0	3.8	3.6	3.6	3.5
44.8	45	9	6.9	5.4	5.0	4.7
44.3	65	11.5	17	8.4	6.0	5.3
			Viscose continuous filament			
73.0	65	11.5	27	15	8.9	7.1
			Nylon staple			
52.2	0	0	2.6	2.5	2.5	2.4
52.9	45	3.5	3.0	2.9	2.8	2.6
53.9	65	4.5	4.3	3.7	3.3	2.9
			Nylon continuous filament			
87.0	65	4.5	4.5	4.0	3.6	3.2
			Vinyon staple			
46.6	0, 45		2.9	2.7	2.6	2.5
45.4	65		3.6	3.0	2.7	2.6
			Saran continuous filament			
70.5	0, 45, 65		3.2	2.9	2.6	2.4
			Fiberglas continuous filament			
63.2	0, 45		3.7	3.7	3.7	3.7
63.2	65		6.0	4.4	3.7	3.6

100 P%*	R.H. (%)	M (%)	100 c./sec.	1 kc./sec.	10 kc./sec.	100 kc./sec.
			Wool			
51.3	0	0	2.8	2.7	2.7	2.6
50.6	45	9	3.8	3.5	3.4	3.3
55.9	65	12	7.4	5.5	4.9	4.6
			Acetate staple			
44.4	0	0	2.6	2.6	2.5	2.5
45.4	45	4	3.1	3.0	3.0	2.9
47.1	65	6	3.7	3.5	3.4	3.3
			Acetate continuous filament			
78.8	65	6	4.1	4.0	3.8	3.7
			Orlon staple			
41.3	0	0	3.4	2.8	2.5	2.3
41.6	45	1.5	4.0	3.3	2.8	2.5
41.8	65	2	5.7	4.2	3.3	2.8
			Extracted Orlon staple			
37.8	65	2	3.2	2.8	2.6	2.5
			Acrilan staple			
54.6	0, 45		2.9	2.7	2.6	2.5
53.7	65		3.6	3.0	2.7	2.6
			Extracted Dacron staple			
47.8	0, 45, 65		2.4	2.3	2.3	2.3
			Ardil			
39.3	0		2.8	2.7	2.7	2.6
39.6	45		3.5	3.2	3.1	3.0
38.4	65		4.8	3.8	3.5	3.3

* Value through which the extrapolation was drawn.

TABLE III. VALUES FROM THE LITERATURE

Material	f	M (%)	ϵ	$\cos\phi$	Reference
Cotton, transverse	1.755 Mc./sec.	0	3.5*		Balls [4]
	1.755 Mc./sec.	7	9*		
Cotton, axial	1.755 Mc./sec.	0	6*		
	1.755 Mc./sec.	7	16*		
Cotton†	100 c./sec.	0		0.005	New [21]
	1 Mc./sec.	0		0.02	
	100 c./sec.	7		0.4	
	1 Mc./sec.	7		0.025	
Cellophane film	60 c./sec.	0	7.7	0.009	Stoops [32]
	10 kc./sec.	0	7.3	0.016	
	1 Mc./sec.	0	6.7	0.062	
Cellophane	3,000 Mc./sec.	0	4.04		Shaw and Windle [27]
Wood (typical values)	2 Mc./sec.	0	2.05	0.03	Witkopf and Macdonald [35]
	40 Mc./sec.	0	1.95	0.04	
	2 Mc./sec.	7.4	2.9	0.046	
	40 Mc./sec.	7.4	2.67	0.082	
	2 Mc./sec.	13	4.12	0.062	
	4.5 Mc./sec.	13	4.02	0.055 (minimum)	
	40 Mc./sec.	13	3.83	0.075	
Acetate rayon†	100 c./sec.	0		0.005	New [21]
	1 Mc./sec.	0		0.01	
	100 c./sec.	6		0.03	
	1 Mc./sec.	6		0.02	
Keratin film	500 c./sec.	0	5		King [16]
	11 kc./sec.	0	4.5		
	1 Mc./sec.	0	4		
	500 c./sec.	12	9		
	11 Kc./sec.	12	7.5		
	1 Mc./sec.	12	5.5		
Wool	8 kc./sec.	0	5.4		Errera and Sack [10]
	60 kc./sec.	0	4.4		
	120 kc./sec. to 13 Mc./sec.	0	4.2		
Wool and hair	3,000 Mc./sec.	0	3.70		Shaw and Windle [27]
	10,000 Mc./sec.	0	3.54		
Wool†	100 c./sec.	0		0.005	New [21]
	1 Mc./sec.	0		0.01	
	100 c./sec.	12		0.03	
	1 Mc./sec.	12		0.015	
Nylon	10 kc./sec.	0	4.2		Errera and Sack [10]
	500 kc./sec.	0	3.26		
	10 Mc./sec.	0	3.15		
Nylon	11 kc./sec.	0	4		King [15]
	11 kc./sec.	4	8		
Nylon	3,000 Mc./sec.	2	3.13		Shaw and Windle [27]

* Extrapolated.
† Arbitrary degree of packing.

TABLE IV. Optical Frequencies; Squares of Refractive Indices, n, of Dry Fibers [13, 19]

Material	$\epsilon = n^2$, with light vibration: Parallel to fiber axis	Perpendicular to fiber axis
Cotton	2.56	2.28
Viscose rayon	2.43	2.28
Acetate rayon	2.19	2.16
Wool	2.44	2.38
Nylon	2.50	2.31
Orlon	2.26	2.26
Acrilan	2.31	2.32
Dacron	2.89	2.35
Glass	2.39	2.39

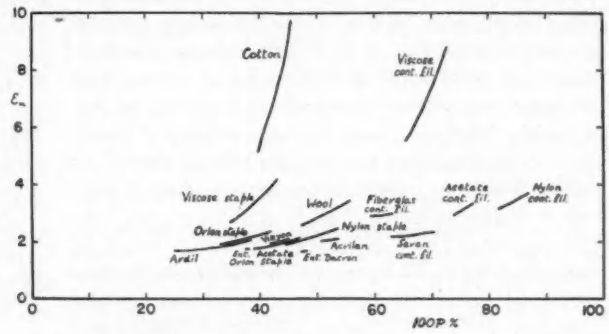


Fig. 26. *Dielectric constant of various materials; 65% R.H., 70°F, 1 kc./sec.*

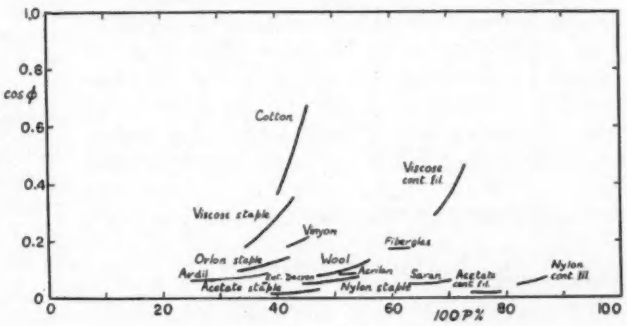


Fig. 27. *Power factor of various materials; 65% R.H., 70°F, 1 kc./sec.*

Discussion

Effect of Frequency

The dielectric behavior of a material is dependent on the permanent and induced dipoles present in it. In materials containing dipoles having a single relaxation time, the dielectric constant falls and the loss factor and power factor show peaks at the corresponding frequency. In materials with a range of relaxation times, this behavior is less sharp.

All the results of the present experiments show a dielectric constant decreasing as the frequency increases, although the decrease is extremely small with most of the dry specimens. This decrease over the range of 50 c./sec. to 200 kc./sec. must mean that there is a polarization of structural units having relaxation times between 1/50 sec. and 5μ sec. It is interesting to compare this behavior with that of pure water. Liquid water has a constant dielectric constant of 81 up to about 1,000 Mc./sec. [9]. The behavior of ice [29] is shown in Figure 28; it may be seen that the dielectric constant falls rapidly between 5 kc./sec. and 50 kc./sec. in a way similar to that in the fiber curves. This suggests that the ab-

sorbed water molecules are restrained in a manner similar to those in ice. However, in the fibers the dielectric constant curve does not flatten out below 5 kc./sec., but continues to increase as the frequency decreases. This would correspond to a long relaxation time, and must be due to a large-scale polarization phenomenon (in terms of molecular dimensions). Various authors [7, 20, 22] have suggested that the movement of ions in fibers is limited, to some extent, to closed paths; and it is probable that this large-scale effect is due to a polarization of the ion distribution in closed paths.* The longest relaxation times might even be due to the movement of ions across whole fibers. If this mechanism occurs, further study of it might lead to an estimate of values for the actual rate of movement of free ions in the materials (as distinct from the bulk mobility of ions) and for the lengths of closed paths which exist.

The fall in the power factor with increasing frequency, at low frequency, can be explained as due to the gradual failure of the units which carry the D.C. current to follow at full speed the alternations of field. This effect would prevent a maximum from occurring, as in ice. However, the results for cotton at 65% R.H. show a maximum in the power factor at 100 c./sec., moving to higher frequencies in damper conditions. There is also an indication that there may be a maximum at a somewhat lower frequency for viscose rayon staple; continuous-filament rayon gave a maximum at 100 c./sec. at 65% R.H. These results indicate that there is a dominant relaxation time of the order of 1/100 sec. Speculating that this might be due to a movement of ions right across a fiber, it would indicate a rate of ion movement of 0.1 cm./sec.

Table V summarizes the behavior of some of the specimens at the highest frequencies tested. These results suggest that, with these specimens, there is a drop in dielectric constant and a maximum in power factor at some frequency in the range above 200 kc./sec., corresponding to a relaxation time of the order of 10^{-6} to 10^{-8} sec. Some of the results in Table III also support this view. This effect might be due to the movement of absorbed water molecules, or to the movement of polar groups in the fiber molecules.

It is interesting to compare the electrical and mechanical behavior. Horio *et al.* [14] suggested that there are peaks in the mechanical absorption and increases in the real part of the modulus at frequencies of the order of 1 c./sec., 10^{6} c./sec., and 10^{13} c./sec. Horio's low-frequency effect may correspond to the electrical effect shown in the present results

* If only a small fraction of the ions present are free to move (the rest being associated in pairs), then it is only this fraction that would take part in the polarized distribution.

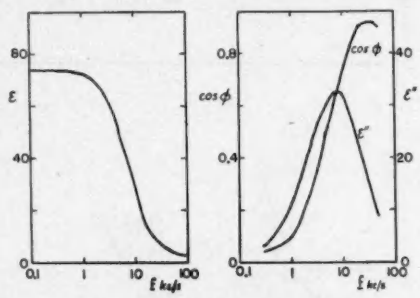


FIG. 28. *Dielectric properties of ice.*

TABLE V. BEHAVIOR OF SOME MATERIALS NEAR 200 KC./SEC.

Material	R.H. (%)	Dielectric constant	Power factor
Acetate rayon	65	Starting to decrease more rapidly	Increasing
Wool	45	Starting to decrease more rapidly	Still decreasing
	65	Starting to decrease more rapidly	Increasing
Nylon	0	Starting to decrease more rapidly	Increasing to 100 kc./sec.
	45	Starting to decrease more rapidly	Doubtful at 200 kc./sec.
	65	Starting to decrease more rapidly	Flat
Orlon	65	Starting to decrease more rapidly	Still decreasing
Ardil	45	Starting to decrease more rapidly	Still decreasing
	65	Starting to decrease more rapidly	Still decreasing
Dacron	0	Flat	Increasing
	45	Flat	Increasing
	65	Flat	Increasing

for cotton; the medium-frequency effect to the electrical effect suggested in the range above 200 kc./sec.; and the high-frequency effect to the drop in dielectric constant occurring between the frequency of 3×10^9 c./sec. used by Shaw and Windle [27, 28] and optical frequencies.

Effect of Moisture

As might be expected, the addition of water to the fibers increases both the dielectric constant and the power factor. This is due to the presence of the polar water molecule, to the freeing of polar groups in the fiber molecule, and to the freeing of ions. At the higher frequencies the water in the cellulose fibers appears to be acting as if it was restrained in a manner similar to the restraints in ice. In this connection it is interesting to note that Kolkmeyer and Heyn [17] observed lines characteristic of ice in the x-ray diffraction pattern of cellulose. For wool the water has a more reduced effect. At lower frequencies in some of the materials (notably cotton, where the dielectric constant reaches very high values) the effect of water becomes greater even than it would be if the water were acting with a dielectric constant of 80, indicating the importance of its effect in allowing other units in the structure to polarize.

Comparison of Different Materials

When dry, the materials tested all gave values for ϵ_m of 2 or slightly less, varying little with frequency. The present method is not accurate enough, under these conditions, to determine any differences which may exist.

But at 65% R.H., differences can be seen, even without a reliable method of extrapolation to $P = 1$. The dielectric constants of the fibers (Figure 26 and Table II) may be arranged in the following order, which may be compared with the order of moisture contents:

Decreasing dielectric constant	Decreasing moisture content
cotton	wool
viscose rayon	viscose rayon
Orlon	cotton
Ardil	acetate rayon
wool	nylon
Fiberglas	Orlon
Vinyon	Acrilan
acetate rayon	Dacron
extracted Orlon	Saran
nylon	Vinyon
Acrilan	Fiberglas
Saran	
extracted Dacron	

Power factor values follow almost the same order as dielectric constant; but it may be seen that there is little correlation with the order of moisture contents. It is only in materials of rather similar structure, such as viscose rayon and acetate rayon, that the differences in dielectric constant and power factor can be explained by differences in moisture content

The difference between cotton and viscose rayon could be due to the difference in molecular organization; but the effect of differing impurities in different materials must not be overlooked as a cause of difference in dielectric properties, especially at low frequencies where ion movement may be important.

Wool, a protein fiber, has a much lower dielectric constant than the cellulose fibers. This must mean that the water molecules absorbed on wool are not as free to orient themselves in the electric field, and have less effect in loosening the units of structure. At higher moisture contents the difference becomes less marked, and there is a rapid rise in the power factor of wool. This fits in with Speakman's [30] suggestion of absorption in three phases. He suggested that the first water molecules are strongly bound to hydrophilic side-chains (—OH, $—NH_3^+$, $—COO^-$, $—CO \cdot NH_2$), where they have no effect on the rigidity and would be expected to have little effect on the dielectric constant. At higher moisture contents the water molecules would be more loosely bound, replacing hydrogen bonds between adjacent peptide groups, and would have a greater effect in increasing the dielectric constant and power factor.

Relation between Electrical Resistance and Dielectric Constant

In a recent paper [12] the following equation based on the dissociation of ion-pairs was proposed:

$$\log R_s = \frac{A}{\epsilon} + B, \qquad (8)$$

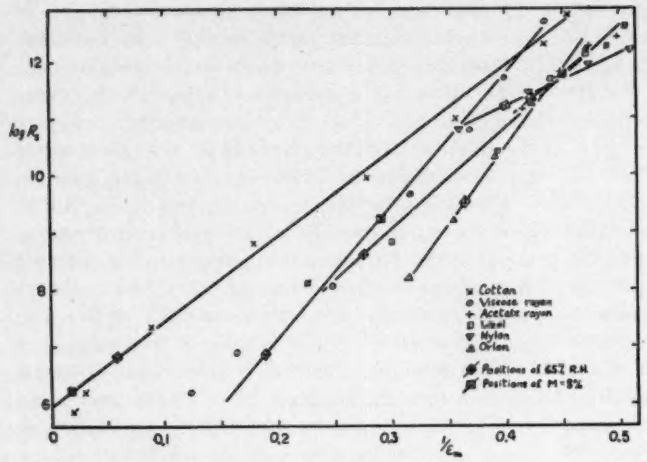


FIG. 29. *Relation of resistance to dielectric constant: log* R_s *vs.* $\frac{1}{\epsilon_m}$ (ϵ_m *measured at 1 kc./sec.*)

where R_s is the mass-specific resistance in ohm-g./cm.^{2}, and A and B are constants.

In Figure 29 values of log R_s at various moisture contents (taken from previous work [11]) are plotted against $1/\epsilon_m$ (the values of ϵ_m being corrected to $P = 0.5$). It may be seen that the results for a particular type of fiber fit straight lines well, and that, although A and B need not necessarily be the same for different types of fiber, the results do group closely together. Thus, the present results support the validity of the equation, even though actual values of ϵ, instead of ϵ_m, could not be used to test it. It is also difficult to decide which is the appropriate frequency to use.

Included in Figure 29 are the positions of 65% R.H. and $M = 8\%$ on the various lines. The wide dispersion of these indicates that the relation between resistance and dielectric constant is not the result of a mutual correlation with moisture content. It also makes the grouping of the results more significant.

Conclusion

Although no satisfactory method of extrapolation could be found, the present results give information on the dielectric properties in terms of their variation with frequency, moisture condition, and materials. This has various practical applications. For instance, the results show that in order to minimize the effect of moisture on evenness testing, a high frequency should be used; whereas in order to secure the most sensitive moisture testing, a low frequency would be best.

Some suggestions have been made as to the interpretation of the results in terms of the structure of the material. If values of dielectric constant and power factor could be obtained over a wider range of frequency and moisture conditions, and at various temperatures, the dielectric properties might be a source of much information about the structure of fibers and the behavior of their constituents.

There is further evidence in support of the relation between electrical resistance and dielectric constant.

Acknowledgments

The author wishes to thank Dr. H. M. Brown and other members of the Faculty at Clemson for their advice and discussion. He is also indebted to the United States Government for an award under the Smith-Mundt Act; to Clemson College for its hospitality; and to the College of Technology, Manchester, England, for giving the author a leave of absence during the period in which this work was carried out.

Literature Cited

1. Argue, G. H., and Maass, O., *Can. J. Research* **B13**, 156 (1935).
2. Baker, W. O., and Yager, W. A., *J. Am. Chem. Soc.* **64**, 2164 (1942).
3. Baker, W. O., and Yager, W. A., *J. Am. Chem. Soc.* **64**, 2171 (1942).
4. Balls, W. L., *Nature* **158**, 9 (1946).
5. Böttcher, C. J. F., "Theory of Electric Polarisation," Amsterdam, Elsevier Publishing Company, 1942, p. 415.
6. Böttcher, C. J. F., *Rec. trav. chim.* **4**, 47 (1945).

7. Boyer, R. F., *J. Appl. Phys.* **21**, 469 (1950).
8. de Luca, H. R., Campbell, W. B., and Maass, O., *Can. J. Research* **B16**, 273 (1938).
9. Dorsey, N. E., "Properties of Ordinary Water Substance," New York, Reinhold Publishing Corporation, 1940, p. 359.
10. Errera, J., and Sack, H. S., *Ind. Eng. Chem.* **35**, 712 (1943).
11. Hearle, J. W. S., *J. Textile Inst.* **44**, T117 (1953).
12. Hearle, J. W. S., *J. Textile Inst.* **44**, T177 (1953).
13. Heyn, A. N. J., TEXTILE RESEARCH JOURNAL **22**, 514 (1952).
14. Horio, M., Onogi, S., Nakayama, C., and Yamomoto, K., *J. Appl. Phys.* **22**, 966 (1951).
15. King, G., *J. Colloid Sci.* **2**, 551 (1947).
16. King, G., *Trans. Faraday Soc.* **43**, 601 (1947).
17. Kolkmeyer, N. H., and Heyn, A. N. J., *Proc. Konink. Nederland. Akad. Wetenschap.* **37**, 92 (1934).
18. Lichtenecker, K., *Physik. Z.* **27**, 115 (1926).
19. Mauersberger, H. R. (editor) "Matthews' Textile Fibers," New York, John Wiley & Sons, Inc., 1947, p. 60.
20. Murphy, E. J., and Lowry, H. H., *J. Phys. Chem.* **34**, 598 (1930).
21. New, A. A., *Elec. Commun.* **19**, 71 (1940).
22. O'Sullivan, J. B., *J. Textile Inst.* **39**, T368 (1948).
23. Polder, D., and von Santen, J. H., *Physica* **12**, 257 (1946).
24. Rayleigh, J. W., *Phil. Mag.* **34**, 481 (1892).
25. Reddish, W., *Trans. Faraday Soc.* **46**, 459 (1950).
26. Skaar, C., New York State College of Forestry, Syracuse, N. Y., Technical Publication No. 69, 1948.
27. Shaw, T. M., and Windle, J. J., *J. Appl. Phys.* **21**, 956 (1950).
28. Shaw, T. M., and Windle, J. J., *Phys. Rev.* **91**, 218 (1953).
29. Smyth, C. P., and Hitchcock, C. S., *J. Am. Chem. Soc.* **54**, 463 (1932).
30. Speakman, J. B., *Trans. Faraday Soc.* **40**, 6 (1944).
31. Stöcker, E., *Z. Physik.* **2**, 236 (1920).
32. Stoops, W. N., *J. Am. Chem. Soc.* **56**, 1480 (1934).
33. Weiner, O., *Abhandl. math. phys.-Klasse sächs. Akad. Wiss. Leipzig* **32**, 509 (1912).
34. Weir, C. E., *J. Research Natl. Bur. Standards* **48**, 349 (1952).
35. Witkopf, J. J., and Macdonald, M. D., Engineering Experiment Station, Oregon State College, Bulletin No. 28, 1949.

(Manuscript received September 28, 1953.)

GORDON RESEARCH CONFERENCE ON TEXTILES

Colby Junior College, New London, N. H., July 12–16, 1954

Individuals interested in attending the Conference are requested to send in their applications to W. George Parks, Director, Department of Chemistry, Rhode Island State College, Kingston, Rhode Island, on or before May 15, 1954.

George S. Buck, *Chairman*

July 12—T. F. Cooke	—"The Mechanism of Wrinkle Resistant Finishes for Cellulosic Fabrics"
Herman F. Mark	—"Recent Developments in the Synthetic Fiber Field in Europe"
July 13—Allan McQuade	—"Recent Work on Flame Resistant Treatments for Textile Fabrics"
R. H. Peters	—"A Study of the Initial Stages of the Dyeing Process"
July 14—C. B. Havens	—"Preparation and Properties of Fibers from Vinylidene Chloride"
Alex Brown	—"Second-Order Transition Temperature and Fiber Properties"
July 15—Nils Gralén	"Fiber Friction at Different Velocities"
Herbert G. Lauterbach	—"Felts from Man-Made Fibers"
July 16—Newton A. Teixeira	—"A Theoretical Analysis of the Mechanism of Tongue-Tear in Woven Fabrics"

Papers Presented
at
T. R. I. ANNUAL MEETING
NOVEMBER 12-13, 1953

The State of the Institute*

J. H. Dillon†

STAGING the Annual Meeting of Textile Research Institute, as you might suspect, is quite a task. You will find people at Princeton running around in circles, and the Chairman and other members of the Annual Meeting Committee worrying, tearing their thinning locks for several weeks before the affair comes off. This involves also the publication of the Annual Report, which generally is delivered from the printer the night before the meeting begins. Sometimes in the course of these vigorous and nerve-straining preparations we wonder whether the Annual Meeting is worth while. When the day of the meeting comes, we are still wondering about it, but generally as the sessions proceed we begin to realize that it is worth the effort.

I do think the Institute has done rather a good job in the last few years in bringing before you prominent figures of the textile industry, particularly men of great technical record and ability to present topics of current interest. I think it is a fine opportunity for people of the industry to get together and renew acquaintanceships and discuss their problems in an informal way. Furthermore, as far as the staff and other people of the Institute are concerned, once the meeting is under way, there is a great satisfaction in finding four or five hundred people of the industry who are sufficiently interested in the Institute to attend. Some of you come from considerable distances; all of you are busy men and women, and we appreciate the interest which you show in coming here.

Now you will note from this year's program that there has been a considerable departure from those of previous years. First, we have two all-day sessions scheduled rather than three half-day programs. Second, we have had a comprehensive survey of Institute research results during the past year given by our Director of Research, Dr. Wakelin—a brief and concise summary, it is true, but rather complete. This was done simply because we have found many people criticizing us for not talking enough about Institute work and emphasizing perhaps too much the work of other organizations. Finally, as a departure from precedent, it seemed that this year you might be interested in having someone from the Institute give an informal picture of where we stand, what we are shooting for, and some recent T.R.I. developments. Hence, I am not going to give you a luncheon address; have no fear. Rather, I shall talk very informally, first about the general status of the Institute, secondly to give you a picture of a few recent developments since the beginning of this fiscal year, September 1, 1953, and finally a few thoughts about the Institute's future prospects and what will be necessary in order to accomplish our aims in the future.

Before I plunge into the general status report on the Institute, I think it might be well to clear up a

* Presented at the Annual Meeting of Textile Research Institute in New York City, Nov. 12, 1953.

† Director, Textile Research Institute, Princeton, N. J.

few misconceptions which exist concerning the Institute, its objectives, and its operations. These misconceptions become apparent to us in the course of our rather voluminous correspondence and discussions with people of the industry. For example—the other day I found a gentleman who had long been interested in the Institute who was convinced that all of the publications in Textile Research Journal stem from research done at the Institute. I have had this same thing happen a number of times, particularly with industry executives, and the strange thing about it is that some of them were not quite satisfied that T.R.I. was doing much of a job. This would have meant that the Institute was carrying out about half of the textile research in the whole world, which I think would have been rather commendable on our present budget of something over $300,000 a year. Nevertheless, this misconception actually exists, and I want to clarify it right now to say that of the papers in Textile Research Journal, only 12% to 15% of them are reports of Institute research, and we feel rather proud that we contributed thirty papers to the Journal and to other technical publications last year.

Now I am also quite sure that a number of people are not aware of the real objectives of Textile Research Institute, or have forgotten what they are. So, let's just recite them very briefly and then discuss what they mean. The first thing we are trying to do is fundamental research—the type of research which supplies basic data which the applied scientists can use. In slang, it might be called filling that old bucket of scientific principles from which applied scientists and engineers can draw for their practical applications. The second of the three objectives is to produce textile scientists trained at the Ph.D. level to become the future research men of the industry. We are doing this, of course, through a cooperative program with Princeton University. The third objective is a corollary of the other two—we are attempting to disseminate textile research information, principally by publishing Textile Research Journal, the only purely scientific periodical in the textile field of this country. If basic textile research results are not published, both textile research and education have hard sledding. This is just an old axiom, well proven, and Textile Research Journal certainly has been a successful endeavor in that direction.

But now consider the basis of these objectives. Those who knew the American textile industry of the early thirties will recall that very little textile research was then going on. Textile Research Institute, then known as the U. S. Institute for Textile Research, was born in this era and it was natural for its founders to set it up on the assumption that it would eventually have broad industry-wide support. Scrutiny of its three main objectives reveals that they were selected on this basis. For a number of reasons the Institute never achieved the status of the sole research center of the American textile industry. Whether this was fortunate or unfortunate is subject to argument. In any event, T.R.I. did gain strong and faithful support, but by only a portion of the textile industry. But the objectives remained essentially unchanged and, in themselves, are still sound. In fact, the principal benefits of membership in T.R.I. today reside in the broad research and educational program with its capability of generating new scientific knowledge and training research men for the textile industry of tomorrow. In my opinion, no firm should become a member of T.R.I. unless it understands that this is the primary function of the Institute and considers its modest dues as a sound investment in the technical future of the textile industry and its allied branches.

Thus far I have discussed only the broad industry benefits of T.R.I. membership. In other words, we have considered T.R.I. as a "worthy cause." It would be unnecessary to say more, were T.R.I. supported by the whole industry, as envisioned by its founders. But the fact is that T.R.I. is supported by only a part of the industry. Hence, a situation exists where a group of 120 firms is supporting an institution which publishes all its research results for the unrestricted use of the whole industry. This may seem unfortunate, for no one can blame a textile executive who wonders why he should bring his company into a group which is apparently giving the rest of the industry a "free ride." He will probably recognize that freedom to publish is a vital requirement in a fundamental research program. But still he may ask, "What's in it for us?"

Now, the Institute's Trustees and the staff, I believe, are realists. We feel that the question, "What's in it for us?" is not only natural, but legitimate. In fact, we have attempted to inject into T.R.I.'s program a set of functions which provide specific benefits to a member company, over and above those constituting the "worthy cause" idea. This has been done without compromising the primary objectives;

suppose now we set down some of the specific benefits briefly, as follows.

As I pointed out before, the Institute, by virtue of the fact that it is dedicated to a program of fundamental research, eventually publishes all its important findings. However, there is no reason why the company membership of the Institute should not be given prior information on results of our research, and we do just this by giving our Company Members confidential monthly progress reports, each on a single subject, called "Notes on Research." Issuing them does not limit or delay publication in the literature. Judging by the response we get from our membership, to whom these reports are issued exclusively, they are finding the mark. They are brief, concise, easy to assimilate, and are intended mainly to stimulate interest and further discussion of the Institute's work. They have done just that, and the Institute membership has these as a specific value or benefit of membership.

Now for the second of these specific values of membership; member companies have the privilege of consultation with members of the Institute staff at any time. Their technical men may come in and talk with us on any subject they choose—their own mill and product problems, or any of the work under way at the Institute. We prefer to talk about problems with which we have had some experience, so we ask them to let us know in advance the subjects which they wish to discuss. Sometimes we can help them—sometimes not. I am glad to say that there has been an increasing number of visitors who come to Princeton to talk about their problems as well as to learn about Institute research. This is a basic function of T.R.I. and constitutes a specific benefit for the membership which will have growing importance as our staff becomes more and more seasoned and their field of activity broadens.

Then, as a third specific value, a member firm may participate in a group-supported Special Project. We have talked about this a great deal. We have the Wool Research Project, the Cotton Research Project, the Dyeing Research Project, etc. These are efforts by groups of members to have us intensify our work in their fields of interest for which, of course, they supply additional funds. Often some of them provide processing equipment and other facilities, so that we can relate our fundamental findings to the practical operations in the mill. This has been done with great effectiveness. The fact that the groups of members thus supporting the projects have advisory committees following the work and joining with us in Princeton in programming it makes it truly a cooperative industry research effort.

Until recently it was not possible for an individual member firm to sponsor a Special Project at the Institute. But finally this last year it was decided that an individual member firm may come in and lay a problem before us. If it is a research problem, not just a control or trouble-shooting problem, if it is well defined, if they are willing to pay for it, if they are willing for the results to be published eventually, and if it doesn't have to be kept under a canvas in the dark we are perfectly willing to tackle it. This, I believe, is going to be another very important means by which the membership may derive specific value from the Institute.

Another specific benefit is the provision for sponsorship of Participating Fellowships. Here a member firm may sponsor a fellowship and suggest the field of research, which, if we find it satisfactory and within our scope, becomes the Fellow's thesis assignment. Thus, the firm not only has the opportunity of having the work done by paying the total cost of the fellowship plus his supervisory fees and so forth, but has the chance of following that graduate student through his career and perhaps employing him when he graduates.

In general, member firms have an open door, one might say, in hiring Research Fellows, because we keep them in touch with the progress of all our current Fellows. If a member firm is interested in employing one of them, they have the first shot at developing contacts.

Another of the specific advantages relates to patent policy. Member firms enjoy patent privileges at the Institute. Patents resulting from the General Research Program become the property of the Institute, of course, just as would be the case in a university, and any income derived from royalties is added to the general T.R.I. research fund. The disposition of patent rights is under control of the Board of Trustees, as it should be, whose general policy is to make such patents available for use by all Company Members on a royalty-free basis. When it is in the best interests of the Institute and its members, however, the right is reserved by the Board to grant licenses, exclusive or nonexclusive, and to determine the amounts of the royalties and other conditions of licensing. Sponsors of Special Projects and Partici-

pating Fellowships enjoy patent privileges relating to the work carried out in their interests, of course, and the minimum privilege is a nonexclusive royalty-free license under patents resulting. Several important T.R.I. patents are now pending. I will talk about this a little later but I do wish to emphasize that the patent policy is very similar to those of some of our universities, and it is designed only to protect the interests of the companies who support the Institute.

Weighing the potential benefits of Institute membership, as I have listed some of them, against the very moderate annual dues ranging from $100 to a maximum of $2250 per year (far less than the cost of one laboratory technician), it would appear that the Institute has provided a pretty good set of answers to the question, "What's in it for us?" It should be emphasized that these are not just theoretical answers. A number of our member companies have been taking advantage of these specific privileges and we have yet to hear a complaint about the value of their associations with the Institute and the cooperativeness of the staff. The magnitude of the benefits derived, of course, is in proportion to the extent of their interest and participation in the Institute's activities. It is most gratifying to the staff when a member company derives value through our work, and it is still more encouraging to us to find that the firms who get the most out of their membership are, without exception, conscious of our broad program and consider its support more of a privilege than of a duty.

Suppose now we talk about a few of the recent developments at the Institute since September 1, which marks the beginning of the present fiscal year. You will remember Dr. Wakelin's discussion of Dr. Mercer's discovery of the bilateral structure of wool; how the wool fiber appears to be made up of two chemically and physically different parts laid together, side by side, perhaps by chemical action in the follicle; how these two parts dye differently; how one can be supercontracted more than the other and thus made chemically vulnerable so that it can be dissolved out by enzyme attack. I think that it was quite clear from his discussion that this finding may make possible the development of new chemical treatments of wool to change its properties, perhaps to make it more feltable, perhaps to make it more stable under certain conditions of stress, temperature, and moisture. Obviously this finding is not only scientifically interesting but may be the basis for important practical advances. But the reason I brought this up was to tell you about a rather interesting experiment that we have planned for the future. One of the experiments which Dr. Mercer performed—the measurement of cystine content of the paracortex remaining after removal of the orthocortex with the enzyme—indicated that the chemically resistant portion, the paracortex, has a higher cystine content than the more reactive orthocortex. However, since he could measure only that and not the part that had been dissolved by the enzyme, he was not satisfied with this experiment. The experiment which we have planned will be done through the helpful cooperation of the Department of Agriculture. This will involve feeding some sheep a diet which includes sodium sulfate labelled with sulfur 35. In other words, we are going to make these sheep develop tracer-labelled cystine in their wool, and we already know from preliminary experiments that this can be done. With this experiment it will be possible for us to take the wool fiber, use Mercer's technique for separating the ortho- from the paracortex, and measure with a Geiger counter the cystine contents of the two portions. This appeals to me as a rather nice experiment although it may not appeal to the sheep.

One more interesting development on which I will bring you up to date—the matter of polymer blends. You will remember that Dr. Wakelin described Dr. White's and Mr. Cates' work in this field. In one portion of their work they blended cellulose acetate and acrylonitrile together in various proportions making homogeneous films which seemed to have rather good mechanical properties and which dyed in proportion to the amount of cellulose acetate present. We announced this finding a few weeks ago to our fiber-producing members, in order to see whether any of them were sufficiently interested to do some work on it with the facilities which they have but which we do not have. I am very glad to say that one company was willing to do this, and we wish to acknowledge with thanks their cooperation. Today I have some yarns which were spun successfully from acetate-polyacrylonitrile polymer blends which you may wish to examine. In other words, instead of blending fibers together to get average properties, to improve moisture absorption and dyeing, here we have yarns where the polymers or molecules of the fibers are blended together. We still don't know whether these yarns are going to be any good. We

don't know, companies who are interested don't know, and I wish to emphasize that we are not announcing a new practical discovery. We are not claiming a new fiber or anything else. We have taken out patents on it simply to protect the interests of T.R.I. supporters. We do not expect to make enormous money out of it for our research fund. Maybe the patents won't even hold water. It is too early to say. But I quote this and Dr. Wakelin quoted this only as a research finding, and I thought you would like to see that yarns have actually been made without difficulty from acetate-polyacrylonitrile blends and that perhaps there is something in this idea. The idea of polymer blends is not original with us except that previous published attempts have been with materials which were more nearly alike chemically than are cellulose acetate and acrylonitrile. So, perhaps some day we shall have acrylic fibers with controlled moisture sorption, dyeing, static properties, and so forth, but we are not bragging now. I ask you all to wait a few years and see what happens and simply to think of this as a possible practical outgrowth of a pure research program on the solubility of fiber-forming polymers.

I might say that the same situation applies as regards the process for the separation of the linear and branched-chain constituents of starch which Dr. Wakelin has described as the results of Professor Pacsu and his graduate student, Albert Bauer. Perhaps some day this work will result in furnishing the industry a nonretrograding soluble starch size—something that has been badly needed for a long time. It may also supply a linear polymer—rather a low-priced linear polymer—which, when chemically modified, may be the basis of fibers, films, and plastics. Perhaps it will furnish a substitute for tapioca pudding, something which I assure you we never started out to develop but which might be an important outgrowth. This is just the result of a research study of the structure of starch, a material of the textile industry and an analogue of cellulose. Again this may prove to be an interesting, practical evolution of a fundamental research study, but we will have to wait for the results of pilot-plant experiments.

Finally, allow me to wind up this little talk with a simple listing of the assets of the Institute.

1. We have laboratories, equipment, and land in Princeton conservatively valued at $274,000, and by the end of this year the remaining principal of our loan (now $4,500) will be reduced to zero. It seems to me that T.R.I. has done pretty well in this respect.

2. We have a staff of forty able people, which we have developed over a period of years—a number of senior scientists, junior scientists, and others—plus fifteen Research Fellows who do valuable research while they are carrying out their graduate studies. This staff is intact. We have had a few staff losses during the past year for the first time, but were most fortunate in replacing them, and this staff is working hard to do the job set out for them. They are available for whatever jobs come to the Institute in the future. Certainly this experienced, able, and congenial staff is an important asset.

3. We have a remarkable working arrangement with Princeton University whereby our Research Fellows are appointed to the Graduate School to carry out their studies, are given their lectures and examinations by Princeton, and are finally granted the Ph.D. degree, if they are successful in their work, by Princeton University. Their doctorate degrees are in chemistry or engineering but they do their doctoral research in the fiber field at T.R.I. This has been a very successful program; the only trouble with it is that it really isn't big enough. We have spent half a million dollars on it in the last six or seven years but that still means only about four or five men graduated with Ph.D.'s each year.

4. Asset No. 4 is TEXTILE RESEARCH JOURNAL. Very little need be said about that splendid publication, which is a monument to the efforts of Julian Jacobs. It should be remarked, however, that it costs us $20,000 net per year to put it out. Sure, this is a vital service of the Institute, but $20,000 is $20,000. We are going to continue it whether or not we develop more advertising to make up this deficit.

Another very great asset is the continually increasing interest of our Company Members in the program and their increasing participation in it. This to me is most significant and something which, if it continues, augurs success for the Institute in the future.

Then, finally, we could mention that more and more we find quite obviously practical results falling out of the fundamental research program. This is just a mark of maturity of any fundamental research program. It always happens if you give it time, if you give it support, and if you are patient. It is going to happen more and more, and this, to me, is not only a present asset but a bright light for the future.

But, let us recognize that the costs of research continue to increase whether we like it or not, even though we maintain the same level of activity. Actually, last year we ran a little in the red, and that's tough because we don't have any cushion to carry us over periods of industry recession. Furthermore, we don't have sizable capital funds to provide us normal increases in laboratory space or for the purchase of new equipment, which any laboratory needs as time goes on. The net of the whole thing is that, if our program is to expand or continue at the present level (and I want to emphasize that), we must gain additional support.

So, in conclusion, it appears to me that the Institute is in pretty good shape and has a reasonably bright future. We have the facilities, we have the staff, and we have the experience to continue to do a good job for the textile industry—a much better job if our support increases. It is a little discouraging at times to find a large company, with net sales in the millions, so concerned about an expenditure of $1,500 per year —less than the cost of one laboratory helper; this is just "peanuts" to that company but an appreciable item of income to T.R.I. In general, however, we are gratified by the continued support and encouragement of our present members. We hope that they will realize something of value on their investments in T.R.I. and trust that others will join with them in encouraging the T.R.I. experiment in textile research and education.

Results of Institute Research in 1953*

James H. Wakelin†

Dr. Wakelin's talk at the meeting was based on his report as Director of Research of T.R.I., which appears in full in the 1952–1953 Annual Report of Textile Research Institute, pages 29–57. Copies of this annual report have been sent to all subscribers of Textile Research Journal and, therefore, his talk is omitted here.

* Presented at 1953 Annual Meeting, Textile Research Institute, November 12, 1953.

† Director of Research, Textile Research Institute.

Ten Thousand and One Customer Complaints*

Jules Labarthe†

Complaints as Warnings

The distance between you and an impending electrical storm may be calculated by counting the number of seconds that elapse between the flash of lightning and the sound of thunder. Seconds are commonly counted by 1001, 1002, etc. If, therefore, you were to regard ten thousand and one customer complaints as the tally count between the spark of consumer irritation with goods and the impact of the storm, your vulnerability would depend a good deal upon the point of reference; that is, did you begin with the count 1001 and proceed all the way up to 10,001, or did you begin with 10,001? If the latter is the case, the storm is really upon us all.

In a not too flourishing textile market, such as we have today, I think it would be far healthier if we were to regard these individual customer complaints as being an implication of an imminent storm of resentment about the way in which our textile customers feel they have been treated.

Before going into detail concerning individual cases and some of the tabulated summaries, let's see just what these customer complaints really are. What is some of the historical background? Why were they sent to the laboratory for evaluation? What were our findings and recommendations in general?

Study Based on Preselected Group of Cases

To begin with, this rather imposing number of individual consumer complaints presents but an infinitesimal percentage of the total number of complaints received by the Kaufmann store, or any other department store, mail order house, or retail establishment during the course of a single year. This collection has taken some 15 years to gather together, for we have had submitted to the Kaufmann Fellowship at Mellon Institute only those customer complaints received by the store in which there was distinct disagreement between the customer and the store representative as to where the responsibility lay. In other words, these were the problem cases submitted to the Fellowship laboratory for the purpose of impartial judgment. In some cases, the merchandise was sent to us because the customer said frankly, "I won't believe it unless I see a copy of what your technical staff says." In other cases, the buyer, realizing that the merchandise may have some serious defect, will wish to have his stand strengthened by a laboratory report when he returns the goods and perhaps any remaining stock to the manufacturer.

Until two years ago, customer complaints of this type could be sent to the laboratory on a test order made out by the buyer, section manager, adjustment manager, or other authorized store person to whom the laboratory would report in due course of time. It was found, however, that we were being used as alibis in many cases that should never have been reported to us so the system was tightened up somewhat by having a member of the Kaufmann Fellowship staff go to the Research Department in the store one day a week, at which time any buyer or other store person having customer complaints to be evaluated, studied, or analyzed by the laboratory would bring these goods for a preliminary screening. In many cases, simple tests could be made in the Research Department and judgment could be reached as to whether the purchaser was justified in her complaint or whether she had misused the article. Problem cases and those requiring more detailed laboratory investigation could then be sent to the laboratory on the usual test order; therefore, we now have sent to the laboratory only about 10% of the items actually seen by us, the other 90% having been judged rather easily and quickly by experienced inspection in the store.

As an example I would like to quote a portion of a letter regarding a corset complaint received from a customer. The first page was a rather uninteresting routine description of the transaction. The cause of complaint is dealt with more fully in page 2 which reads as follows:

* Presented at the Annual Meeting of Textile Research Institute, Nov. 12, 1953.

† Senior Fellow, Mellon Institute, Pittsburgh, Pa.

"When the corset is tightened about my waist and then adjusted to be comfortable in the lower abdomen, the fat comes down and *shows* blow the corset. Then when I sit down it pinches the roll of fat and abdominal walls causes pressure.

When I wear it tight enough to take care of the lower abdomen which is essential, I cannot stupe over and when I sit down it forces my busts up under my chin and disturbs my respiratory action.

Now you have my honest complaint of an unsatisfied customer. What are you going to do about the matter? I ask some lady friends what they would do so we prayed about the matter and now leaving it rest between you and the Lord."

Now I would like to try to forestall or anticipate a few questions about these complaints that you might reasonably ask.

The Significance of a Single Complaint is Great

First, just how many dissatisfied customers will a single justified complaint represent? This question is fundamental and to a considerable degree it is the main reason for my emphasizing the imminence of the storm warning. I have no exact answer, and I wonder whether any one does. I have asked the question of a number of store buyers from time to time, saying "Here is a piece of merchandise that the laboratory and you both agree is of such poor quality or workmanship or material that any customer who bought it might be expected to be unhappy with it. How many did you sell, and how many have you had returned?" Bearing in mind that a buyer might have a certain amount of pride, and therefore would be unwilling to admit that a poor buy had been made, the usual answer is "Why I sold 100 to 150, maybe 300, and this is the only complaint I have received." In defense of the buyers, I would like to say right now that rarely do we have submitted to us two identical products returned by customers. I remember only one distinct exception. The case involved six rayon robes that were so poorly constructed that even hand washing caused the seams to ravel and to open, and the first machine washing ruined every seam in the garment. These six represented almost 200 sales, and I am very sure that the other 194 customers were just about as unhappy as the six who returned the goods. I might say in passing that the manufacturer in this case refused to take back some 70 unsold pieces. The laboratory would not permit them to be sold, and they were eventually given away to an institution. The manufacturer's point was that the goods had been tested by one of our better commercial testing laboratories and had been given an excellent report on washability for colorfastness, low shrinkage, etc. We were in agreement with the other laboratory's findings, but the fabric was of such loose weave that the seams would have required binding or other reinforcement in order to have them hold together in the washing operation. The fault, therefore, lay more with the manufacturer of the garment than with its fabric resource. In other words, most customer complaints are one of a kind, although the same problem fabric may show up in several different items of wearing apparel from different departments over a few weeks' time.

Are There Repeaters?

The second question one man asked is, "Aren't a lot of these customer complaints from chronic gripers?" To that I can only say "I don't think so." We have not made any attempt to identify on our more than 10,000 cards the names of all the customers. I am sure there are a few repeaters, but in general such individuals soon become known to all store adjusting bureaus, and the chronic complainer and returner of goods does not receive much sympathy.

Comparison Checks Made on New Merchandise

As we review some of the tables rather briefly, the question may arise in your mind "Haven't you been a little tough on the customer in many of these cases?" Perhaps we have because, although as a general rule, a new garment from stock from the same shipment as the customer's article is usually referred to the laboratory, our conclusions as to what happened to the goods in service can only be based upon laboratory test methods by which we try to establish the fact whether, if properly handled in washing, cleaning, pressing, wearing, or other exposures in service, normal methods could create the degree of damage found in the customer's article and then to find out what more rigorous handlings or mistreatments might be required to simulate the customer's results. Thus we try to prove whether the goods would behave satisfactorily under normal use-conditions (whatever they may be) and also under

any abnormally severe treatment the customer might have imposed upon them. In this regard we may be too hard on the customer because we are forced to discount what the customer may say she was told she could do. Perhaps the article was dry cleanable only and the customer washed it and will tell us in a letter or in a verbal report made to the store representative that she was assured by the sales person that the article could be washed. Quite frankly, I am fast becoming skeptical of the complete truthfulness of the dissatisfied consumer because very rarely will any housewife admit that she washed the article in question by any other means than "hand washing with either Lux or Ivory flakes." Maybe the article still contains a sufficient concentration of chlorine bleach almost to knock your head off if you bravely smell it without a properly cautious approach. She will never admit to having used chlorine bleach, and she just doesn't know where that chlorine could have come from. On the other hand, we are not so naive as to think that many sales people, being not too well informed about some of the newer fabrics and fibers, are overly prone to simplify their use. We have all collected, I am sure, a rather comprehensive list of fantastic stories that store sales people use in trying to sell a bill of goods. Therefore, maybe at times we are a little more severe on the customers than we should be; and perhaps to some extent also are our findings that they have caused nearly 66% of the damage to articles in this accumulation of 10,001 cases, whereas only about 34% has been attributable to a fault of the merchandise.

Figure 1 shows a typical punch card recording the

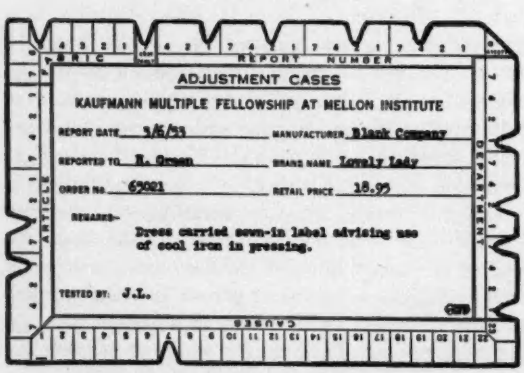


FIG. 1. *Punch card recording pertinent information on a dress complaint.*

pertinent information on a dress complaint. On the face of the card appear some supplementary data identifying the manufacturer, brand name, and the retail price as well as certain remarks and observations. On the right-hand end of the card is punched the department number, across the top is our own report number—in this case No. 1224. On the left-hand end of the top are shown the seven fabric categories (No. 5 being our code for acetate) and along the left-hand end of the card are the punched designations for the article. Code No. 140 punched here is the designation for women's dresses. Along the bottom of the card, there are 23 possible punch spaces for our 23 categories of damage, the last being a miscellaneous one for certain causes which occur rather infrequently. This card is punched for damage No. 7 which is pressing with too hot an iron. Also appearing at the top of the card is an individual punch designation showing whether the consumer or the merchandise is at fault. If this space is punched, it means that the consumer has misused the article and, therefore, no adjustment would be recommended. These consumer complaint punch cards can thus be hand or machine sorted by type of article, fiber, cause of complaint, department, responsible party, or by individual report number.

The first quick sorting of our cards shows the following distribution of complaints: women's wear —7104; men's wear—1330; children's wear—830; other textiles—700. Sorting these cards then by checking whether a punch mark shows the fault to be that of the customer, we have found that our preselected group shows the consumer to have been at fault in 66.1% of the cases and the merchandise to blame for 33.9%. Included in the consumer or user fault category are the cases of mishandling by the laundry or dry cleaner.

Conflicting Designs for Use

All of us here today are interested in textiles, but generally in only one phase or status of fiber development and use. It is significant, I think, that all our efforts to synthesize, to develop, to perfect, to color, to finish, and to apply a new fiber or an old one to a piece of textile material are conscientiously carried out with infinite pains in laboratories throughout the land. However, the results of all this research, quality control, and evaluational study have been carried out on the textile in an entirely different physical structure and form and in different environ-

ments than those used by the final arbiter—the American consumer. These textiles have gone into products. We're not interested so much now in individual fiber properties, yarn properties, or maybe even fabric properties as we are in the ultimate strength, behavior, and service-use of the dress, apron, suit, curtain, rug, or whatever else the article may be. All this research and development have gone into fiber facts, yarn data, and fabric analyses, that may or may not indicate the amount of wear and service life the consumer has the right to expect of the garment. Research and precision testing will guide a new fiber into what the skilled technologist in the laboratory considers to be the appropriate use-conditions; but economics, style, and taste—not test data—will actually channel a new material or a perfected process into the end-use application we had intended it to fulfill. I am convinced that the manufacturer of garments, particularly in women's wear, doesn't give a "continental" about the fiber present in the yardage he buys for a line of dresses unless perchance it contains enough of one of the new glamour names to make it a little extra sales "gimmick" that he can use when he entertains store buyers and shows his line. You can carefully engineer a fabric, but the garment manufacturer will say, "O.K., but how many ends and how many picks can you take out and make it just as good but 5¢ a yard cheaper?" The textile producer may have specified certain dyestuffs or specific finishes to be used, but color and texture can be copied by many cheaper dyestuffs and inferior finishes to confuse and bedazzle the garment manufacturer when he tries to select between your research-developed line and that of the copyist down the street—if the manufacturer is not interested in any other difference than the price. The technical design for use may often yield to the practical and commercial.

Bargains a Lure

All of us, even you and I, welcome a bargain. We, too, are only too prone to take a chance if something seems to be offered to us at a lower price. We hope that we will not be disappointed. We all bite for the "just as good as" line. The store buyer and the store customer alike pay greater attention to the esthetic qualities of merchandise than the utilitarian. Fashion and style may dictate the lines and the colors. They often dictate the texture of the fabric as well, especially in women's wear. We all want to look right in the clothes we buy, or we want our household fabrics to reflect our good taste. The harmony of the new with what we already have often guides us in our selection. Our customer point of view is based on the appearance of a textile product whether it is wearing apparel or household fabric. Wearing qualities are intangibles that have defied our technical appraisal for generations, and they will continue to defy us. It is only when we wear and use these products that we become aware of their serviceability. It is only then that the stress-strain data, the colorfastness values, the permanency of the finish, the resistance of the garment to shrinkage, and the many other plaguing serviceability angles enter in. These are consumer values. They would never bother us if we were simply making fabrics to be made into garments for show and not for use.

Yes, I think 10,001 customer complaints about textiles should have an impact upon the textile industry, even though we cannot say that each individual complaint represents a hundred, or two hundred, or maybe only ten consumers who were equally unhappy with their purchases but who didn't do anything about it other than to gossip away the reputation of the store and of everyone else whose name entered into the product, thus supplying them with unserviceable merchandise. One impact of this is that a justified customer complaint about one new synthesized fiber reacts to the disadvantage not only of that individual fiber and fiber producer but all the others in the minds of an unknown number of customers. A store may satisfy a consumer by giving her full credit or some other adjustment. But what of the others they could not reach? Each dress sold at one store, whether bought originally in lots of a half a dozen or 500, has been bought in like amounts in practically every other city across the country. Therefore, each justified complaint must be multiplied by some large factor, the denomination of which we do not know. Whether we are counting from 1001 upward to 10,001 or whether we are beginning with 10,001 is irrelevant and immaterial. The storm, the indignation, the unhappiness of the consumers or users of many of our finest textile products constitute an existing problem. It is a mass of resentment that we should recognize.

Let us now view some of the tabulated data on individual commodities in order to ascertain in what respects the articles failed in service and whether the consumers' complaints were justified. To begin

with, we find from our 10,001 punch cards that the identity of the principal fibers appears in the following percentages: cotton—21.3%; wool—18.8%; linen—1.1%; rayon—18.8%; acetate—22.5%; silk—4.5%; miscellaneous—13%. The miscellaneous category includes nylon and all of the newer synthesized fibers and also those cards on which the fiber was not identified.

It is interesting to compare these percentage figures with the 1951 fiber consumption in the United States. In that year, the fiber consumption fell in the following percentages: cotton—68.8%; rayon (and acetate)—19.7%; wool—9.3%; all synthesized fibers—2.1%; silk—0.1%. Admittedly, these percentages are not all-revealing because they include other textile applications than apparel and household fabrics.

Table I shows a comparison of the frequency of complaints by various fibers in women's and misses' blouses and dresses, together with the number of garments cut, according to the 1951 Census of United States Manufacturing. It is interesting to note that in the case of blouses and of the "dozen lot dresses" the production figures are expressed in terms of thousands of dozens and that in the case of dresses in this category cotton predominated, whereas in the dresses quoted in individual units, rayon and acetate predominated with 96,500,000 having been produced and accounting for 69.5% of the dresses in this group. In this unit group, the sale of rayon and acetate garments predominated over cotton in every price bracket, even those selling at under $3.00 apiece wholesale. In the $4.00 to $5.99 bracket, there were 9,954 thousand units of cotton garments as against 26,197 thousands of units of rayon and acetate. In the $6.00 to $6.99 bracket, the figures for cotton and rayon (acetate) were 8,282 thousands of units as against 26,969. From this point on to $31.00 and over, the numbers of thousands of units decreased but the preponderance in favor of rayon and acetate was constantly increasing. This table shows that the percentage of complaints and percentage of garments manufactured in cotton, and in rayon and acetate combined, show the same general order of magnitude.

Table II shows the specific breakdown by cause of damage of 1438 blouses. It will be noted that causes No. 1 to 13 inclusive and No. 23 are generally the result of consumers' misuse of the article, and causes 14 to 22 inclusive are generally the fault of the merchandise. This is a generalization because, for example, all cases of shrinkage on washing or dry cleaning (damage No. 4) are not the fault of the person handling the goods. In some cases when a new garment is checked against the customer's garment, it is found that even the most careful washing or dry cleaning does produce shrinkage, and in those cases the garment is not "punched" as being the fault of the consumer. The shrinkage in this case is attributed to the fault of the merchandise. Similarly, in causes 10 and 11 which involve wear, occasionally merchandise is found that is so fragile that it will not give good serviceability, and in these cases the merchandise is decided to be at fault and an adjustment is given. Similarly, cause of damage No. 16—sun fading of dye can at times be found to be the fault of the customer in the misuse of an article or from exposure to sunlight for a much longer period than one might reasonably anticipate. The

TABLE I. COMPARISON OF PERCENTAGE OF COMPLAINTS AND PRODUCTION BY FIBERS IN WOMEN'S AND MISSES' BLOUSES AND DRESSES

	Blouses			Women's dresses				
		Garments cut*			Garments cut*			
					Unit dresses		Doz. lot dresses	
	Complaints (%)	M/doz.	(%)	Complaints (%)	M/units	(%)	M/doz.	(%)
Cotton	14.3	3985	32.9	20.4	32547	23.5	6791	80.0
Wool	1.8	428	3.5	2.5	5052	3.6		
Linen	2.0			1.9				
Rayon	14.7	6514	54.0	29.1	96500	69.5	1646	19.2
Acetate	48.0			29.1				
Silk	6.2			4.2				
Nylon	2.1	939	7.8		1165	0.8		
Miscellaneous	10.3	183	1.5	12.8†	3294	2.4	71†	0.8
Total	99.4	12049	99.7	100.0	138558	99.8	8508	100.0

* 1951 Census of U. S. Manufacturing.
† Including nylon and all other fibers not listed.

totals ascribed to consumer and to merchandise responsibility on these several tables are those resulting from actual sorting of the cards; not by totalling causes 1 to 13 inclusive and 23 as being consumer faults and 14 to 22 inclusive as being the responsibility of the merchandise. In other words, poor serviceability of the merchandise sometimes occurs in those types of failure most commonly attributed to consumer misuse, and similarly this handling of the goods on the part of the consumer can cause damage of those types most commonly associated with merchandise failure. It will be noted, too, from Table II that the most common cause of damage in blouses is careless ironing with 328 blouses being damaged from this cause, 311 of these being acetates. This leaves an open question, however, and that is to what extent this cause of damage might have been avoided had the garments been more factually labeled and the fiber clearly identified with specific ironing directions? It is interesting to note, too, that the second largest category of damage is from perspiration or the careless use of an anti-perspirant. Most housewives fail to realize the acid nature of many of the anti-perspirant preparations, and they do not follow the directions for using these materials with the result that their garments—especially the cellulosic ones—are seriously weakened. The most significant failure on the part of the merchandise is in the slippery nature of these fibers and yarns, and shifting of the yarns accounts for 101 of the 1438 of the garment damage cases. Faulty garment construction such as skimpy seams, poor fit, and fabric flaws accounts for 58 complaints, and improper processing such as holes in discharge prints, the development of odor in crease resistant finished rayons and acetates accounts for 49.

TABLE II. Breakdown of Customer Complaints on Women's Blouses

	Cotton	Wool	Linen	Rayon	Acetate	Silk	Nylon	Miscellaneous	Total
Generally customer at fault (1–13 incl. and 23)									
1. Perspiration or antiperspirant (holes)	80		20	13	14	7		36	170
2. Perspiration or antiperspirant (color change)	1			5	5	3		5	19
3. Perspiration (dye bleeding)				2				1	3
4. Washing or dry cleaning (dimensional change)	14	7	1	19	29	5	1	11	87
5. Washing (color damage)	10			14	15	10	4	7	60
6. Washing (holes, rips)	3	4		28	44		1	3	83
7. Ironing (scorching, glazing, melting)	2		1	3	311	4	2	5	328
8. Staining and spotting (wearing or bleaching)	7	2		12	20	10		9	60
9. Corrosive chemicals (holes, including bleach damage)	26		2	2	9	2	1	1	43
10. Wear strain (holes, rips, cuts)	21	2	1	22	40	12	4	16	118
11. Wear abrasion (worn areas)	5	1	1	8	15	3	5	7	45
12. Heat or burning (damage except from hot iron)	1			1	4	1	1		8
13. Insects (moth and carpet beetle holes, etc.)		4							4
Generally merchandise at fault (14–22 incl.)									
14. Seam failure	1			2	3				6
15. Sun rotting of fabric									
16. Sun fading of dye	1			2	1	8		5	17
17. Gas or atmospheric fading				1	24			6	31
18. Garment construction (seams skimped, poor fit, flaws)	4	2	1	15	18	4	3	11	58
19. Shifting of yarns	3			17	60	17	2	2	101
20. Improper processing (odor, print holes, etc.)	7			16	20	1	5		49
21. Faulty sales information (labels and claims wrong)	1				27				28
22. Crocking or rub-off of dye (dry or wet)	11	2	1	10	12	9		11	56
23. Miscellaneous (dermatitis, mildew, etc.)	7	2	1	19	19	3	1	12	64
Total	205	26	29	211	690	99	30	148	1438
Dollars	815	164	181	979	2979	669	253	600	6640
Customer	163	19	27	130	519	69	19	110	1056
(%)	79.5	73	93	61.6	75.3	69.7	63.3	74.4	73.5
Merchandise	42	7	2	81	171	30	11	38	382
(%)	21.5	27	7.0	38.4	24.7	30.3	26.7	25.6	26.5

TABLE III. BREAKDOWN OF CUSTOMER COMPLAINTS ON WOMEN'S DRESSES

	Cotton	Wool	Linen	Rayon	Acetate	Silk	Misc.*	
Generally customer at fault (1–13 incl. and 23)								
1. Perspiration or antiperspirants (holes)	100	5	15	72	61	9	75	337
2. Perspiration or antiperspirants (color change)	3	4		26	42	8	10^{2}	93
3. Perspiration (dye bleeding)	4	4		21	14	2	2^{1}	47
4. Washing or drycleaning (dimensional change)	37	5	3	37	23	4	15^{1}	124
5. Washing (color damage)	69		6	39	48	11	17^{1}	190
6. Washing (holes and rips)	10	1		59	12	2	3^{1}	87
7. Ironing (glazing, scorching, melting)	7		2	7	112	3	11^{1}	142
8. Staining and spotting (wearing or bleaching)	40	2	5	33	88	11	28^{1}	207
9. Corrosive chemicals (holes, including bleach damage)	65	2	5	23	17	2	12	126
10. Wear strain (holes, rips, cuts)	46	5	1	102	29	11	45^{7}	239
11. Wear abrasion (worn areas)	16	10	2	34	22	5	17	106
12. Heat or burning (damage except from hot iron)	4	1		4				9
13. Insects (moth and carpet beetle holes, etc.)	5	5						10
Generally merchandise at fault (14–22 incl.)								
14. Seam failure	9			2	3	1	2	17
15. Sun rotting of fabric	15							15
16. Sun fading of dye	3	2	2	7	5	7	12	38
17. Gas or atmospheric fading				6	193		2	201
18. Garment construction (seams skimped, poor fit, flaws)	4	5	1	28	13	2	8^{1}	61
19. Shifting of yarns	1	4		35	17	4	7	68
20. Improper processing (odor, print holes, etc.)	19	4	4	100	34	6	25^{2}	192
21. Faulty sales information (labels and claims wrong)				8	1	1		10
22. Crocking or rub-off of dye (dry or wet)	54	3	4	86	14	18	21^{2}	200
23. Miscellaneous (dermatitis, mildew, etc.)	25	4	2	36	16	5	25^{1}	113
Total	536	66	52	765	764	112	337	2632
Customer	347	44	37	429	378	56	242	1533
Merchandise	189	22	15	336	386	56	95	1099

* Superscript nos. represent number of nylon samples in misc. group.

TABLE IV. BREAKDOWN OF CUSTOMER COMPLAINTS ON MEN'S SUITS

	Cotton	Wool	Linen	Rayon	Acetate	Misc.	Total
Generally customer at fault (1–13 incl. and 23)							
1. Perspiration or antiperspirants (holes)							
2. Perspiration or antiperspirants (color change)		4			1		5
3. Perspiration (dye bleeding)		2					2
4. Washing or drycleaning (dimensional change)	2	2	1				5
5. Washing (color damage)	1				1		2
6. Washing (holes and rips)		7		1			8
7. Ironing (glazing, scorching, melting)		2					2
8. Staining and spotting (wearing or bleaching)	1	5		1	2		9
9. Corrosive chemicals (holes, including bleach damage)	1	3		2		1	7
10. Wear strain (holes, rips, cuts)	1	24		3			28
11. Wear abrasion (worn areas)	3	31		1			35
12. Heat or burning (damage except from hot iron)		3					3
13. Insects (moth and carpet beetle holes, etc.)		4					4
Generally merchandise at fault (14–22 incl.)							
14. Seam failure							
15. Sun rotting of fabric							
16. Sun fading of dye		5		1			6
17. Gas or atmospheric fading		3					3
18. Garment construction (seams skimped, poor fit, flaws)		1					1
19. Shifting of yarns							
20. Improper processing (odor, print holes, etc.)		8	1			1	10
21. Faulty sales information (labels and claims wrong)							
22. Crocking or rub-off of dye (dry or wet)		3					3
23. Miscellaneous (dermatitis, mildew, etc.)		37		5	2		44
Total	9	144	2	14	6	2	177
Customer	9	115	0	13	6	2	145
Merchandise	0	29	2	1	0	0	32

TABLE V. Breakdown of Customer Complaints on Men's Shirts

	Cotton	Wool	Rayon	Acetate	Misc.	Total
Generally customer at fault (1–13 incl. and 23)						
1. Perspiration or antiperspirants (holes)	1	1			2	4
2. Perspiration or antiperspirants (color change)			2	2		4
3. Perspiration (dye bleeding)	1			1		2
4. Washing or drycleaning (dimensional change)	9	2	1	2		14
5. Washing (color damage)	13			3	3	19
6. Washing (holes and rips)	4		4	2		10
7. Ironing (glazing, scorching, melting)	1			7	2	10
8. Staining and spotting (wearing or bleaching)	29	2	3	2	4	40
9. Corrosive chemicals (holes, including bleach damage)	87		1	1	7	96
10. Wear strain (holes, rips, cuts)	22		2	2	7	33
11. Wear abrasion (worn areas)	16	1	3	3	5	28
12. Heat or burning (damage except from hot iron)	1				1	2
13. Insects (moth and carpet beetle holes, etc.)		1				1
Generally merchandise at fault (14–22 incl.)						
14. Seam failure						
15. Sun rotting of fabric						
16. Sun fading of dye						
17. Gas or atmospheric fading						
18. Garment construction (seams skimped, poor fit, flaws)	6			1		7
19. Shifting of yarns	1					1
20. Improper processing (odor, print holes, etc.)	4		1	2		7
21. Faulty sales information (labels and claims wrong)				1		1
22. Crocking or rub-off of dye (dry or wet)	6	2	1			9
23. Miscellaneous (dermatitis, mildew, etc.)	21	1	2			24
Total	222	10	20	29	31	312
Customer	188	10	16	26	27	250
Merchandise	34	0	4	3	4	62

TABLE VI. Breakdown of Customer Complaints on Men's Trousers and Slacks

	Cotton	Wool	Linen	Rayon	Acetate	Misc.	Total
Generally customer at fault (1–13 incl. and 23)							
1. Perspiration or antiperspirants (holes)							
2. Perspiration or antiperspirants (color change)				1			1
3. Perspiration (dye bleeding)		1					1
4. Washing or drycleaning (dimensional change)	2	14		2	1		19
5. Washing (color damage)	5						5
6. Washing (holes and rips)				1	1	1	3
7. Ironing (glazing, scorching, melting)		2			1		3
8. Staining and spotting (wearing or bleaching)	1	21		4	1	5	32
9. Corrosive chemicals (holes, including bleach damage)	7	14		1		7	29
10. Wear strain (holes, rips, cuts)	4	29		2		8	43
11. Wear abrasion (worn areas)	5	48			1	1	55
12. Heat or burning (damage except from hot iron)	2	2					4
13. Insects (moth and carpet beetle holes, etc.)		14				2	16
Generally merchandise at fault (14–22 incl.)							
14. Seam failure				1			1
15. Sun rotting of fabric							
16. Sun fading of dye				2		1	3
17. Gas or atmospheric fading							
18. Garment construction (seams skimped, poor fit, flaws)		5			1		6
19. Shifting of yarns		1					1
20. Improper processing (odor, print holes, etc.)	1	3		2	1	2	9
21. Faulty sales information (labels and claims wrong)							
22. Crocking or rub-off of dye (dry or wet)	3	3					6
23. Miscellaneous (dermatitis, mildew, etc.)	2	12		2		1	17
Total	32	169		18	7	28	254
Customer	26	140		11	6	24	207
Merchandise	6	29		7	1	4	47

Table III gives a similar breakdown for women's dresses. This table does not separate housedresses from street dresses. However, it is a fairly safe assumption that the majority of the cotton dresses would be of the housedress type, some of course being the more dressy cottons for afternoon wear and some also for sportswear; whereas the rayon, acetate, and silk garments would be principally for afternoon wear. In this dress table is a breakdown for 2632 dresses and 1533 were found to be the fault of the consumer use of the article. Only 1099 were attributable to the fault of the merchandise. Here, again, cause No. 1—holes due to perspiration or antiperspirants—accounted for the greatest number of customer complaints; thus, in general, the wearer was at fault. Strain in wear and staining and spotting were the next two most important consumer misuse categories. On the other hand, the three most common merchandise faults were gas or atmospheric fading of acetate, crocking off of the dye during wearing, and improper processing, referring again to the development of an odor through improperly developed and fixed crease resistant finishes, print holes, etc.

Tables IV, V, and VI deal with three items of men's wear—suits, shirts, and trousers and slacks. As anticipated, wool is the most important fiber in the suits and in the trousers and slacks. Thus far, we have had so few complaints on the synthesized fibers in men's wear that they have not been separately identified. We have had some cases of pilling which would be classified under cause No. 11—worn areas from abrasion. The miscellaneous category, cause No. 23, is unusually high in the case of men's suits. A rather large number of cases of skin irritation from coarse weaves appears in this group. Included, too, are those cases where a customer says a suit will not hold its crease.

Table VII shows a breakdown of the customer complaints on children's dresses that have failed in service. Careless washing, staining and spotting, and holes resulting from damaging chemicals (including organic acids from soft drinks left on the fabric and then 'freshened' by pressing) are the principal causes of damage which may be attributed to misuse on the part of the wearer or of the person cleansing the garment. Inadequate colorfastness to

TABLE VII. BREAKDOWN OF CUSTOMER COMPLAINTS ON CHILDREN'S DRESSES

	Cotton	Wool	Linen	Rayon	Acetate	Misc.	Total
Generally customer at fault (1–13 incl. and 23)							
1. Perspiration or antiperspirants (holes)	6					1	7
2. Perspiration or antiperspirants (color change)							
3. Perspiration (dye bleeding)							
4. Washing or drycleaning (dimensional change)	3	1					4
5. Washing (color damage)	15			1	3	2	21
6. Washing (holes and rips)				1			1
7. Ironing (glazing, scorching, melting)			1	2	5	1	9
8. Staining and spotting (wearing or bleaching)	10			1	1	1	13
9. Corrosive chemicals (holes, including bleach damage)	22			1		2	25
10. Wear strain (holes, rips, cuts)	14	1					15
11. Wear abrasion (worn areas)	7					1	8
12. Heat or burning (damage except from hot iron)	1						1
13. Insects (moth and carpet beetle holes, etc.)							
Generally merchandise at fault (14–22 incl.)							
14. Seam failure	1			2			3
15. Sun rotting of fabric							
16. Sun fading of dye	1						1
17. Gas or atmospheric fading					3		3
18. Garment construction (seams skimped, poor fit, flaws)	4	1	1	4		1	11
19. Shifting of yarns				2	2		4
20. Improper processing (odor, print holes, etc.)	6			3	2		11
21. Faulty sales information (labels and claims wrong)					2		2
22. Crocking or rub-off of dye (dry or wet)	9			5	2		16
23. Miscellaneous (dermatitis, mildew, etc.)	6		1	1	1	2	11
Total	105	3	3	23	21	11	166
Customer	77	3	3	18	15	8	124
Merchandise	28	0	0	5	6	3	42

TABLE VIII. GENERAL SUMMARY OF CUSTOMER COMPLAINTS BASED ON TYPES OF MERCHANDISE

Women's wear

	Cotton		Wool		Linen		Rayon		Acetate		Silk		Misc.		Total	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)	No.	(%)	No.	(%)	No.	(%)	No.	(%)
Dresses	536		66		52		765		764		112		337		2632	
Customer	347	64.5	44	66.5	37	71.0	429	56.0	377	49.3	56	50.0	243	72.0	1533	58.4
Merchandise	189	35.5	22	33.5	15	29.0	336	44.0	387	50.7	56	50.0	94	28.0	1099	41.6
Skirts	29		47		4		27		31		6		11		155	
Customer	20	69.0	39	83.0	3	75.0	20	74.0	25	80.6	4	66.7	7	63.6	118	76.0
Merchandise	9	31.0	8	17.0	1	25.0	7	26.0	6	19.4	2	33.3	4	36.4	37	24.0
Jackets and Suit Coats	13		19		1		24		11		1		17		86	
Customer	9	69.1	15	79.0		0	18	75.0	6	54.6	1	100	8	47.0	57	66.3
Merchandise	4	30.9	4	21.0	1	100	6	25.0	5	45.4		0	9	53.0	29	33.7
Suits	11		58		2		26		61		9		1		168	
Customer	5	45.5	41	70.7	2	100	12	46.2	32	52.5	7	78.0	1	100	100	59.5
Merchandise	6	54.5	17	29.3	0	0	14	53.8	29	47.5	2	22.0		0	68	40.5
Coats	16		214		—		13		16		—		49		308	
Customer	6	37.7	160	74.8	—		9	69.3	4	25.0	—		29	59.2	208	67.5
Merchandise	10	62.3	54	25.2	—		4	30.7	12	75.0	—		20	40.8	100	32.5
Raincoats	37		10		—		28		21		2		10		108	
Customer	24	65.0	6	60.0			10	35.7	16	76.2	1	50.0	5	50.0	62	57.4
Merchandise	13	35.0	4	40.0			18	64.3	5	23.8	1	50.0	5	50.0	46	42.6
Blouses	205		26		29		211		690		99		178		1438	
Customer	163	79.5	18	69.2	27	93.0	130	61.6	518	75.0	69	69.7	129	72.4	1054	73.6
Merchandise	42	20.5	8	30.8	2	7.0	81	38.4	172	25.0	30	30.3	49	27.6	384	26.4
Sweaters	9		323		—		5		1				11		349	
Customer	4	44.5	277	83.5	—		3	60.0	1	100	—		9	81.8	294	84.3
Merchandise	5	55.5	46	16.5			2	40.0		0			2	18.2	55	15.7
Bathing Suits	24		45		—		62		46		5		57		239	
Customer	13	54.2	35	77.7	—		40	64.5	41	89.3	5	100	37	64.8	171	71.5
Merchandise	11	45.8	10	22.3			22	35.5	5	10.7		0	20	35.2	68	28.5
Playclothes	35		6				19		10				6		76	
Customer	18	51.5	4	66.6			13	68.4	7	70.0			2	33.3	44	58.0
Merchandise	17	48.5	2	33.4			6	31.6	3	30.0			4	66.7	32	42.0
Pajamas, Robes and Gowns	82		11				80		59		38		40		310	
Customer	54	65.8	10	90.8			46	57.5	31	52.5	29	76.3	28	70.0	198	64.0
Merchandise	28	34.2	1	9.2			34	42.5	28	47.5	9	23.7	12	30.0	112	36.0
Slips	4						59		75		79		88		305	
Customer	3	75.0					46	78.0	67	89.3	72	91.2	71	80.6	259	85.0
Merchandise	1	25.0					13	22.0	8	10.7	7	8.8	17	19.4	46	15.0
Total	1001		825		88		1319		1785		351		805		6174	
Customer	666	66.5	649	79.6	69	78.4	776	58.8	1125	63.0	244	69.5	569	70.8	4098	66.3
Merchandise	335	33.5	176	20.4	19	21.6	543	41.2	660	37.0	107	30.5	236	29.2	2076	33.7

reasonable service conditions account for almost all the 42 dresses found to be at fault.

In addition to blouses and dresses for women and misses, there are other items of wearing apparel about which consumers have complained. Their totals, however, have not been as significant as in these other two categories, but a general summary is given in Table VIII showing the number of garments in each fiber classification and for each the number and the percent of consumer caused damage and merchandise faults. The totals, taken across the column, give the results for each commodity and the percentage decided for the customer or in favor of the merchandise. The vertical totals show the additions by fiber and the percentages of cotton, wool, etc. that have been misused by the customer or in which the merchandise was at fault.

In one important category—women's dresses—we have summarized in Table IX any trends in change of customer complaints since 1935. Thus in this table, we have taken 1935 to 1941 inclusive, 1942 to 1945—the war years, 1946 to 1947—the first years after the war, and then in two year spans since then and up through September 1953. The data indicate that in the last two year period there is a higher percentage of color change due to perspiration and of dye bleeding from this same cause than in any other span. Likewise, shrinkage on washing, failure in wear, faulty garment construction, and improper processing of the cloth all reach new highs. Color bleeding from washing accounts for a higher percentage in 1952–1953 than in any other period except 1950–1951. Surely these facts challenge the textile dyer and processor!

Tables X and XI show for women's bathing suits and for women's blouses the trends toward change

TABLE IX. TRENDS IN CUSTOMER COMPLAINTS SINCE 1935 ON WOMEN'S DRESSES

Causes	1935–1941	(%)	1942–1945	(%)	1946–1947	(%)	1948–1949	(%)	1950–1951	(%)	1952–1953	(%)
1. Antiperspirant or perspiration (holes)	224	16.6	8	2.8	14	8.8	37	14.7	39	9.9	24	4.6
2. Antiperspirant or perspiration (changes color)	36	2.7	24	8.4	5	3.1	4	1.6	12	3.0	37	7.1
3. Perspiration (dye bleeding)	14	1.0	7	2.4	2	1.2	1	.4	13	3.3	19	3.6
4. Washing (shrinkage)	39	2.9	19	6.6	11	6.9	17	6.7	30	7.6	48	9.2
5. Washing (color affected)	60	4.4	24	8.4	3	1.9	14	5.6	52	13.2	50	9.6
6. Washing (excessive strain while wet) and felting of wool	61	4.5	3	1.0	1	.6	5	2.0	13	3.3	23	4.4
7. Ironing with too hot an iron	93	6.9	19	6.6	8	5.0	12	4.8	7	1.8	15	2.9
8. Staining liquids (stain or bleach)	66	4.9	22	7.7	13	8.1	14	5.6	30	7.6	33	6.3
9. Corrosive chemicals (holes caused by acids, bleaches, etc.)	60	4.4	7	2.4	8	5.0	19	7.5	28	7.1	14	2.7
10. Strain during wear (rips, cuts, etc.)	136	10.1	25	8.7	15	9.3	13	5.2	30	7.6	50	9.6
11. Abrasion during wear (holes, shiny spots, roughened areas but not shifting)	49	3.6	6	2.0	6	3.8	13	5.2	22	5.6	31	5.9
12. Heat or burning (holes, scorch, melting except for hot iron in pressing)	4	.3	4	1.4					1	.3	1	.2
13. Moths	3	.2	1	.3					1	.3	1	.2
14. Seam breakage	4	.3	2	.7					3	.6	8	1.5
15. Sun rotting of fabric	—	—	—	—	—	—	—	—	—	—	—	—
16. Sun fading of dye (or discoloration)	24	1.7	4	1.4	4	2.5	2	.8	3	.6	12	2.3
17. Atmospheric fading of dye	110	8.1	68	23.8	10	6.2	14	5.6	11	2.8	11	2.1
18. Construction of garment (not fitted right, too small seams, etc.)	30	2.2	10	3.5	7	4.4	11	4.4	8	2.0	35	6.7
19. Shifting of yarns	20	1.4	9	3.1	11	6.9	16	6.3	13	3.3	6	1.2
20. Processing of material (discharge print holes, finishes causing defects, bad odor, etc.)	120	8.9	7	2.4	6	3.8	16	6.3	38	9.6	51	9.8
21. Inadequate or improper sales information (absence of proper labels, cautions, etc.)	2	.1	2	.7					3	.6	2	.4
22. Dye crocks or rubs off	102	7.6	—	—	28	17.5	31	12.3	28	7.1	39	7.5
23. Miscellaneous (snagging, dermatitis, mildew, etc.)	87	6.8	15	5.2	8	5.0	13	5.2	10	2.5	10	1.9

in fiber as reflected in the customer complaints. Table X shows that the wool bathing suit of 1935 to 1941 is no longer with us. It also shows that there were more customer complaints about bathing suits in 1952 and 1953 than in any other period of our laboratory experience. Reference can be made to Table VIII showing the status of women's bathing suits on the basis of individual fiber classifications.

Care Information Needed

We in the store laboratory field find ourselves as middlemen between you, the producers and technologists, and the ultimate consumer. Part of our duty is to help translate in consumer or customer terms the facts made available to us through your technical reports and your advertising. We are very conscious not only of the great dearth of accurate information but also the amount of misinformation supplied in advertising and in labels. I will admit that there is greater scarcity of any information than there is presence of wrong information. However, if we have one rayon dress, for example, with a washability label and on the same rack is another rayon dress with no label at all, both the sales girl and the customer are very likely to carry over to the second the information supplied for the first. The chances are that the one labeled is the better garment, and that the second one is actually not washable by any household procedure. This kind of customer complaint is common and probably accounts to a considerable extent for conflicting points of view when such merchandise is returned. In many cases, it is obvious that for one reason or another the garment should never have been washed. I can cite a specific example illustrative of the absence of information that I looked at in the laboratory recently. This did not involve rayon but was a woman's dress of wool and Dynel. The customer had never worn the dress, but immediately after purchasing it, made a trip to New York. Perhaps she was not a very careful packer; at any rate, when she opened her suitcase, she decided the dress needed a little touch-up pressing especially around the hemline. The dress was sent to the hotel tailoring shop, and there it was pressed with too hot an iron causing the Dynel fibers to melt and giving a black streak around the hem. The customer said the tailor told her the fabric was defective. Now obviously this was not a defective fabric; however, nowhere in the dress nor in a new one from stock was there any label, tag, or other identifying medium calling attention to the fact that this garment required pressing with a cool

TABLE X. Trends Toward Change in Fiber as Reflected in Customer Complaints on Women's Bathing Suits

	1935–1941	(%)	1942–1945	(%)	1946–1947	(%)	1948–1949	(%)	1950–1951	(%)	1952–1953	(%)
Cotton	6	5.0	2	20.0	2	40.0	3	6.4	4	9.8	4	2.8
Wool	45	37.5					2	4.2				
Linen	—										—	
Rayon	26	21.7	7	70.0	3	60.0	7	14.9	16	39.0	77	54.6
Acetate	6	5.0					21	44.7	8	19.5	45	31.8
Silk	5	4.2									—	
Miscellaneous	32	26.7	1	10.0			14	29.8	13	31.7	15	10.6
Total	120		10		5		47		41		141	

TABLE XI. Trends Toward Change in Fiber as Reflected in Customer Complaints on Women's Blouses

	1935–1941	(%)	1942–1945	(%)	1946–1947	(%)	1948–1949	(%)	1950–1951	(%)	1952–1953	(%)
Cotton	120	15.8	26	8.4	13	13.7	20	16.8	17	15.3	37	27.8
Wool	13	1.7	1	.3	2	2.1	2	1.7	7	6.3	4	4.0
Linen	22	2.9	1	.3	—		2	1.7	3	2.7	4	4.0
Rayon	100	13.2	59	19.1	11	11.6	13	10.9	25	22.5	19	14.3
Acetate	294	38.7	217	70.2	69	72.6	74	62.2	30	27.0	19	14.3
Silk	71	9.3	3	1.0	—		8	6.7	11	9.9	16	12.0
Miscellaneous	140	18.4	2	.6	—		—		18	16.2	34	25.6
Total	760		309		95		119		111		133	

iron. In the customer's garment there was no permanent label identifying the fabric as being wool and Dynel and, of course, the original hang tag was no longer present. This was, of course, on the fact of it, the fault of the tailor, but it is a typical example of lack of information vital to the correct use and service of a new fabric. Therefore, we recommended full credit for the customer and directed that this dress be returned to the manufacturer as an example of lack of proper information.

Textiles for Specific End-Uses

In our contacts with consumer groups (and members of our Fellowship give somewhere between 30 and 40 lectures and talks a year), we are always told by the consumers present that they would be willing to pay a premium (unidentified as to amount) for goods of guaranteed serviceability whether they be rayons, wools, cottons, or made of any other fiber or blend. I think this is a challenge that the textile industry should accept. Let us find out whether a line of, let us say, superior fabrics could be guided into the proper end-use items and sold to the stores and to their customers for whatever slight increase might be required in order to maintain and to police such an operation. If the consumer does not respond by buying these items and continues to buy only on price, then we will have a sound argument for saying, "You had your chance to prove what you have said in the past and we are now convinced that all you want is price, if it can be had together with appearance." This may be had in fabrics of almost any service quality from the best to the worst. If, however, the consumers really live up to their promise and to the preachings of their teachers and advisors in the home economics field, the program could mushroom and spread with tremendous velocity. The first real chance we have to enter this kind of program is in the rayon and acetate fields by having some fabrics and some garments made to conform to the American Standard recently promulgated through the American Standards Association's Committee L-22 and under the sponsorship of the National Retail Dry Goods Association. The next step, of course, would be for the textile industry to try to expand this program into the same end-use items made of other textile fibers—somewhat along the line of the ASA Committee L-24 work on textile fabrics and products made of textiles used by institutions. This program is being sponsored by the American Hotel Association. We need a stronger program for correctly identifying the fibers used in fabric blends; not so much that the presence of 15% of nylon will mean a great increase in durability nor that the presence of 30% of Acrilan will improve greatly the hand of a rayon, but because these additive fibers will mean some kind of plus values in serviceability and will almost inevitably require certain modifications in care methods.

How the Manufacturer Benefits

You have seen that the two fundamental divisions in which these 10,001 complaints have been divided are (*1*) whether they are the fault of the customer and (*2*) whether the fault lies with the merchandise. In the first case, which is the larger in percentage, we do have the chronic gripers. We also have those customers who have made a serious mistake in the care of an article and who unreasonably have requested credit. We also have, however, those customers who might not have made the mistake had the article been better labeled and more competently sold to them and, I might say, more competently sold to the manufacturer and even to the store buyer. In the second group, we have all shades of merchandise faults from criticism because of incomplete or wrong sales information to merchandise of such poor quality that it is almost incomprehensible that every article sold would not have been returned by a customer. It is my feeling that this kind of complaint, as unhappy and as embarrassing as it may be for a store, should serve a useful purpose. Of course, the store can make this customer happy by giving her credit, but the buyer has not lived up to his responsibility as "the purchasing agent for his community" if he has stoically accepted the loss and has simply thrown away this ruined garment. The information should be passed back to the garment manufacturer with or without other stock remaining unsold in that store if the merchandise is bad enough to warrant that somewhat drastic step. Unless the manufacturer learns of such faults, how is he to be expected to correct them in his next season's run? Perhaps he has not tested his goods, and I am sure that in the women's wear field at least he rarely has done any testing of the merchandise he buys. He is at the mercy of his own desire to pick up a bargain and may blindly have bought markedly inferior fabric, binding, thread, or some other component which eventually causes the garment to fail in service.

In other words, he should be in a position to put pressure upon his fabric resource for merchandise of satisfactory quality. This procedure could go back indefinitely through each element in the textile production chain until the real responsibility was pinpointed. I would like to refer briefly to one or two specific examples where prompt action on the part of the buyer was of help to the manufacturer, and I can cite other examples where the manufacturer regarded such information as an outright insult to his intelligence.

About three years ago, only two weeks after its purchase in the store, the laboratory received a woman's blue acetate suit, the shoulders of which had faded to a pink after a dry cleaning made necessary two days after the customer bought the garment. The suit looked as if it had pink epaulets. Obviously it was attributable to either gas fading or acid fading of the acetate. We found it to be the fault of a neoprene binder used in the cotton filled shoulder pads in order to stabilize them and prevent them from sagging and becoming deformed during cleaning. The action of the dry cleaning solvent on this latex created an acid vapor of sufficient strength to affect the light blue dye. The manufacturer happened to be in Cleveland, and he flew to Pittsburgh that afternoon. He came out to the laboratory, took one look at this suit and at some of our little test pillows we had made with his suiting material as well as with the AATCC gas fading fabric, and called the plant on long distance telling them to discard his new "stabilized shoulder pads" and go back to the previous year's material. Then he said, "I've got to pull back from stores some of these treacherous colors, and I have now in the retail market six million dollars' worth of goods at the retail price." The point is that through accident this suit was evaluated quickly. Normally it might have been another month or six weeks before one of these suits would have been cleaned. Perhaps it might have happened in some other store that did not have any laboratory facility available to it. Certainly many thousands more of these troublesome suits would have been in the hands of consumers had it not been for this accident.

I have already mentioned the case of the housecoat as one of the rare ones in which we had as many as six complaints of one identical item, and where the manufacturer would not agree that he had any responsibility whatever in spite of the fact that he sold many thousand dollars worth of merchandise a year to the store I represent. I assure you that any merchandise bearing that manufacturer's name that comes in as a customer complaint is going to receive most critical examination because if he is as dumb a buyer of goods as he is a seller I think we should investigate his products thoroughly.

Who is to Specify Qualities?

As I have been talking to you, I have been dunking this small white bathing suit-clad doll in clear water. Bathing suit manufacturers are another rather hard-headed lot who seemingly place full blame for poor colorfastness of dyestuffs to sunlight and to bleach and poor durability as far as abrasion is concerned on the shoulders of the consumer. One bathing suit manufacturer to whom I had written after we had given credit for a considerable number of his bathing suits wrote back and said, "We will be only too glad when the consumer requests better and more durable colors and more sturdy fabrics in her swim suit." By what medium other than complaining about poor serviceability is the consumer to carry her message to this manufacturer? The fact that some 20 or more of his bathing suits had worn out in the seat within the first week or month of their purchase did not seem to indicate to him anything other than some consumers were unreasonable and that most of them were still satisfied. The fabric used in the bathing suit of this doll was cut from a rayon satin bathing suit returned to us by a young lady who said in her letter, "When this suit became wet, it got transparent. I didn't dare get out of North Park pool until after dark, and I got hell from my family when I got home." Maybe this bathing suit doesn't show as pink to you from the distance at which you are sitting, but I assure you that when the bathing suit is wet out one can put one's hand under the fabric and see every line in the palm of the hand. My point is that no textile manufacturer ever intended this satin to go into a swim suit but that is where it went, and customers are saying, "All light colored rayon swim suits become transparent when they are wet," or they are saying, "The lifeguard at my pool won't permit a white bathing suit on the premises." You see, some guidance must be given to the channelling of your fabrics into the most appropriate end-uses if more and more customer complaints such as these I have cited are not going to result. Remember this, too, that if at any place along the development

line from the fiber to the garment any one of the manufacturing processors has tried to cut corners and reduce the worth of the goods, the chiseler's name and identity will rarely be on any piece of sales information, on any tag, or on any label. The man who shaved off a few cents in processing, in finishing, in dyeing, or in any other kind of textile operation, or who tried to chisel by using cheaper thread, padding, binding, or other findings, will not be identified. The first responsibility, of course, does rest with the store that bought and then sold the article, but the store buyer concentrating on the style element rarely knows much about the durability and serviceability of the component parts. If it is a fashion item, there is never time to have the store's laboratory make any kind of appraisal of the merchandise. Therefore, the buyer must depend upon the reputation of the resource and for that reason any poor buying in terms of serviceability should and must be returned for only then can the manufacturer begin the long tracing back through the chain of textile production to find the guilty party.

In conclusion, I am convinced that the large number of customers will be willing to buy the better products at a somewhat higher price if they can be assured that they will get superior serviceability. I am convinced, too, that some store buyers are now enough interested in such things as the rayon standards to begin to pressure their resources for them for a certain percentage of their stock. I am also convinced that there is nothing more damning to a reputation of an old fiber or a new one than a cheap garment or article made from that fiber by a chiseler. I am convinced, too, that these 10,001 customers will rebuy those things which have given good service and will just as quickly and even more permanently reject new fibers and finishes which have proved to be disappointing because they were guided into the wrong products at the wrong time and at the wrong price.

Some Chemical Experiments on Wools*

Harold P. Lundgren†

IT is the objective of investigations on wool at the Western Regional Research Laboratory to strengthen the wool growing and wool manufacturing industries by application of basic physical and chemical science to the unsolved problems that now limit those industries. These investigations, though limited in scope, are integrated into two closely related phases of investigation: (*1*) fundamental investigations on composition, quality evaluation, and preservation, comprising physical, chemical and biochemical studies aimed to provide the necessary background of basic data for improvement of fibers and improved processing techniques, and (*2*) applied investigations aimed to adapt the basic information to improved treatments and processing of wool and mohair covering all phases of processing from scouring of grease wool to servicing of the finished garment or item.

With further knowledge of wool as a raw material and the conditions and mechanisms of its reactions, it is hoped that we can move in such directions as greater protection of natural good qualities during use life of wools and also toward chemical modification to improve and adapt wools for various uses.

This discussion will deal briefly with several aspects of the work at the Western Regional Research Laboratory. For the most part, this work is still in the basic science stage; in some instances the work is well along in the process towards application.

Aqueous Cleaning of Wools

Two phases of cleaning wool in aqueous systems have been studied [1, 2, 3]. In the one attention has been paid to the removal of grease and dirt from raw wool by suint salts, and in the other we have compared a number of proteins and several synthetic polymers as whiteness retention agents for aqueous laundering of fabrics. In the first investigation a new method for scouring raw wool has been discov-

* Abstract of talk given at the Annual Meeting of the Textile Research Institute, November 13, 1953.

† Western Regional Research Laboratory, Albany, Calif. Bureau of Agricultural and Industrial Chemistry, Agricultural Research Service, U. S. Department of Agriculture.

ered in which butyl alcohol is added to water to 3% concentration to enhance grease removal by the suint salts. The suint salts are perspiration residues normally present in all raw wool, and comprise a wide range of fatty acid salts, but chiefly of about 3 to 5 carbons.

The recovery of grease from the aqueous butyl alcohol emulsion is facilitated when the butyl alcohol concentration is increased to 6%, when phase separation occurs. These principles are employed in a laboratory-scale continuous scouring procedure in which the wool is scoured, the grease and suint recovered as by-products, and the butyl alcohol is recycled. The process has not been reduced to commercial practice.

Our studies of whiteness retention in aqueous cleaning are aimed towards improving laundering practice through furthering present understanding of the mechanism of soil suspension in cleaning formulations. This work should also assist in improving methods of scouring raw wool in those cases where the wools scour out gray due to excessive soil redeposition.

The problem of soil redeposition has attracted attention in recent years. The lack of soil-suspending power of many cleaning formulations can be made up to some extent by using appropriately sodium metasilicate or sodium polyphosphate as the alkali, but carboxymethyl cellulose is much more effective as a suspending agent. Little is known of the precise mechanism of action of these agents.

We have compared the whiteness-retention properties of a number of proteins and related synthetic materials. For purposes of studying mechanisms we have employed a laboratory evaluation procedure in which carbon is used as a test soil. Carbon is electrically charged similarly to most common soils. We have compared several detergents together with alkaline builders. Among the proteins found highly effective for preventing deposition of carbon on wool, as well as cotton, fabrics are a water-soluble gliadin from wheat, soluble reduced feather keratin, and gelatin. The whiteness-retention power of a considerable number of proteins tested falls in the order of their relative abundance of the amino acid proline, and among synthetic polymers it was found that polyvinylpyrrolidone is particularly effective. Also effective is partially acetylated polyvinyl alcohol.

Among the soluble polymers tested, it was found, in general, that the nonionogenic types were more effective that the nonionic ones. An optimum in molecular size for maximum effectiveness was observed in several which were available in a range of sizes. With polyvinylpyrrolidone this optimum lies in the neighborhood of 40,000 molecular weight.

Chemical Modification of Wool

By virtue of its many reactive chemical groups, wool undergoes modification by a host of chemical agents. Modification in certain instances leads to improvement in one or more textile qualities, such as shrinkage or moth resistance. Of numerous chemical treatments of wool which have been proposed, few meet all requirements. Many treatments are unsatisfactory for reasons of cost; in some cases the hand of the wool is so altered that it becomes undesirable for ordinary purposes; in other cases the modification leads to chemical degradation of the fiber with resulting loss in wear life. Moreover, certain treatments are not permanent, either because they fail to resist the normal cleaning and laundering operation or else they undergo chemical change with time, leading to decreased utility of the treated wool. It is anticipated that with further knowledge of the mechanism of chemical modification of wools and establishment of the conditions for optimum treatment, there may develop new and more satisfactory modification and processing treatments than have been available heretofore.

We have adopted this point of view in our studies of wool modification at the Western Regional Research Laboratory. Among several chemical modification treatments that are being studied, the reactions in some cases involve polymer formation *in situ;* in other cases the reaction is merely with reactive protein side chain groups within the fiber.

Frequently the same treatment will impart quite different properties to the fiber depending upon the degree and sites of reaction. I shall illustrate this briefly in the case of beta-propiolactone [4, 5, 6, 7].

Propiolactone is highly reactive chemically with water or any group on a molecule which carries an active hydrogen. Since the wool is of protein nature, it has numerous active hydrogen sites capable of reaction with propiolactone. But in order for reaction to occur within the fiber, it is essential that the fiber structure is open. No reaction occurs within the dry fiber. Opening of the fiber structure is accomplished by swelling in water. Water, on the other hand, decomposes unreacted propiolactone;

therefore, in the presence of excess water the modification in wool is very slow. Consequently, an optimum in modification rate occurs at a certain water concentration. Chemical analysis shows that the propiolactone reacts with several amino acid residues, including those of histidine and lysine. X-ray analysis shows that as the reaction continues the propiolactone forms polymers within the fiber, having a characteristic x-ray diffraction pattern. On mechanical analysis the modified fiber shows interesting characteristics. Whereas most treatments of wool with polymer-forming agents lead to a stiffening of the fiber, the treatment with propiolactone acts to plasticize the fiber. At low uptakes the modified wools still possess the ability to recover from long range extension. In other words, the modification causes little or no damage to the stabilizing cross linkages. The principal effect of modification treatment appears to be the wedging apart of the hydrogen-bonded protein chains. At higher uptake the strength of the fiber decreases appreciably.

Perhaps the most striking effect of the treatment with propiolactone is the increase in felting power of wool, attributable to the increased internal mobility of the fiber structure. This improvement in felting, which increases rapidly beyond 25% uptake, reaches a maximum at around 60% uptake. Beyond 60% uptake the felting power decreases, probably on account of decrease in differential surface friction attributable to excess deposition of the polymer on the fiber surface. Above 150% uptake the fiber exhibits marked shrink resistance.

Assisting this study of modification is a technique which involves the dye, rhodamine-b. Penetrating fiber structure as a molecular probe, this dye reveals available chemical binding sites, and as a result of the modification of wool with propiolactone, new sites for dye binding become available in the wool structure.

Wools differ in the rates with which they undergo modification with propiolactone and this difference appears useful for comparison of wools. We have compared the modification of wool from 5 pure breeds of sheep raised in the same environment on the same diet, representing a wide range of fineness. The breeds represented, in their order of wool fineness, were Rambouillet, Columbia, Suffolk, Navajo, and Lincoln. For the most part the rates of modification with propiolactone increase with fiber diameter independently of breed type. The wool from the Suffolk breed is an exception; it reacts more rapidly with propiolactone than its order in fineness would indicate. Significantly, the untreated Suffolk wool also exhibits mechanical properties out of line with its fineness and attributable to its more highly crimped condition than wools of similar fineness.

Among other chemical modification treatments receiving attention are those which hold promise in stabilizing wool against damage by alkali, acids, light, and abrasion and degradation by moths and other biological agents. It is found, for example, that wool reacts with certain alkenyl succinic anhydrides, and that this modification leads to enhanced stability of the disulfide bonds towards chemical reduction. This stabilization occurs to an equal degree on two classes of disulfide bonds detectable by refined methods of stress relaxation analysis. Modification with acrolein is likewise of interest, since it introduces new possibilities for crosslinking and polymer formation.

We anticipate, finally, that from more precise knowledge of the sites, conditions, mechanisms, and limitations of modification reactions gained from intensive study of typical reactions, such as propiolactone with wool, there may develop more satisfactory modifications of wool than have been available heretofore.

Literature Cited

1. Fong, W., and Lundgren, H. P., TEXTILE RESEARCH JOURNAL **23**, 769–75 (1953).
2. Fong, W., Yeiser, A., and Lundgren, H. P., TEXTILE RESEARCH JOURNAL **21**, 540 (1951); U. S. Patent 2,655,428 (assignee U. S. Secretary of Agriculture) (Oct. 13, 1953).
3. Fong, W., and Ward, W. H., (manuscript in preparation).
4. Jones, H. W., and Lundgren, H. P., TEXTILE RESEARCH JOURNAL **21**, 620 (1950).
5. Lundgren, H. P., and Binkley, C. H., *J. Polymer Sci.* (in press).
6. Rose, W. G., and Lundgren, H. P., TEXTILE RESEARCH JOURNAL **23**, 930–36 (1953).
7. Rose, W. G., Lundgren, H. P., and O'Connell, R. A., (manuscript in preparation).

Optical and Electron Microscopic Studies of Cotton Fiber Structure*

Mary L. Rollins and Verne W. Tripp†

Abstract

The appearance, growth, and structure of a cotton fiber are described, and photomicrographs and electron micrographs are used to illustrate both gross and fine features of the cell wall morphology.

Heretofore, microscopy of the fiber has been limited to the use of dispersion, swelling and staining methods, in plain and polarized light. The development during the present study of methods for isolation of individual components of the cell wall for purposes of electron microscopy has permitted interesting observations with the light microscope. Quantitative measurements of shrinkage in the isolated primary wall of the cotton fiber during mercerization confirm its restrictive influence on the fiber during swelling in various agents.

Electron microscope studies have been made on isolated primary wall fragments which have been purified by removal of noncellulosic constituents by extraction. These have revealed that the cellulosic portion of the membrane is a network of fibrils interlaced in a sort of fabric in which the general system of orientation is axial on the outer surface and transverse on the inner surface. The cellulose framework is impregnated with a complex of waxes, pectinaceous, and proteinaceous substances.

The first layer of secondary thickening, called the "winding layer," has been isolated from 17-day old cotton fibers and photographed with both optical and electron microscopes. It is revealed to be a continuous sheet or layer made up of alternating bands of fibril bundles which spiral about the fiber at an angle. The wider bands have a closely packed parallel arrangement of fibrils while the narrower bands which connect them consist of two systems of fibrils at right angles to one another in an open-weave pattern.

Electron micrographs of fragments of the main body of the secondary wall show an entirely different pattern of fibril arrangement from either the primary wall or the winding layer.

In spite of the tremendous growth of the synthetic fiber industry in recent years, cotton still holds 71% of the world's fiber production market [4]. It is the most versatile of textile materials and the most widely used, but, although its commercial utilization dates back into antiquity, its properties and characteristics are still not completely known. As in the case of most natural products, empirical methods of handling, developed through the ages, still govern modern technological procedures to some extent. Even in the advanced state of our knowledge with respect to physical and chemical phenomena, there are still small areas of ignorance which continue to impede our progress in the improvement of natural products to meet modern needs. The same "miracle" processes which have produced the synthetic competitors of cotton could, it is believed, be used to impart to cotton some of the properties which have given to the synthetics specific advantages in specialized fields. To this end, it is imperative that we understand more thoroughly the morphological and structural features of the cotton fiber itself.

Much of what is known about the appearance, structure, and properties of the individual cotton fiber is the result of microscopical investigations extending over a period of approximately 100 years, in which the most significant advances have come within the past three decades. Two types of microscopes are now in fairly common use: the ordinary light microscope, for which the limit of useful magnification is about 1000, and the electron microscope which can magnify up to 20,000 times directly, but has sufficiently high resolution that the image obtained at 20,000 can subsequently be enlarged photographically to a magnification of 100,000. This instrument, in use for only about 15 years, has already permitted investigations of structure on an entirely different level and, having only recently extended our knowl-

* Presented at the Annual Meeting of the Textile Research Institute in New York City, Nov. 12, 1953.

† Southern Regional Research Laboratory, Southern Utilization Research Branch, Agricultural Research Service, U. S. Department of Agriculture, New Orleans, La.

edge of the structure of natural fibers, promises to contribute materially to our understanding of their behavior during processing treatments.

Fiber Growth and Development

The cotton fiber itself is a seed hair, a single-celled botanical entity which grows from the epidermis of the seed. Seed hairs of one kind or another are common throughout the plant kingdom; familiar types are those of dandelion, thistle, and milkweed. In cotton, however, the hairs are much longer and occur on the seed in greater numbers.

It is believed that in some varieties of cotton the infant fibers spring up on the embryo seed on the day of flowering, while in other varieties it is from one to two days later before they can be seen. It has been estimated that the total number of fibers on a single seed often exceeds 10,000. In most commercial varieties another crop of short, stubby hairs arises as an "undergrowth" or fuzz beneath the longer fibers. They always remain much coarser and shorter than the lint fibers and do not become suitable for spinning; as "linters" they eventually find commercial use in upholstery and as a source of cellulose pulp in the rayon, film, and explosives industries.

Once the young fiber is out, its growth is phenomenally rapid. It increases in length until sometime between the fifteenth and twentieth day, and a fiber may reach in that time a length more than 4000 times its diameter. During all the while the fiber is elongating it is an oval tube consisting of a thin cellulosic cell wall or membrane, called the primary wall because it is the first part of the wall to form. The tube is filled with protoplasm and is plump with the pressure of liquids drawn from the stem of the plant.

Between the fifteenth and twentieth day the fiber almost ceases to grow in length, and thickening of the wall sets in. Layer after layer of cellulose is deposited, one inside the other, all within the thin primary wall. This layering was first shown to correspond to the number of days of growth in 1923 by Balls [3], the English botanist, who likened the layers to the growth rings in the stump of a tree. Later, Kerr [2, 7] confirmed the findings of Balls and showed that each growth ring is made up of two layers, one compact and the other porous—the first associated with warm periods of growth during daylight and the second with growth during cool night hours.

The actual diameter of the growing fiber and the degree of cell-wall development are largely inherited characteristics, but weather and soil environment also greatly influence the latter. Some fibers die before they receive all the layers of cellulose they would otherwise have. Others, retarded in growth because of reduced moisture or food supply, are still underdeveloped at the end of the growing period. After growth ceases, in 40–70 days after flowering, the boll dries out. The cell, formerly distended with plant juices, collapses into a wrinkled, twisted, flattened tube, which is actually often more ribbon-like than cylindrical. The fiber is often tapered for a short length at the tip, and along the length it twists frequently, the direction of twist reversing from time to time. These twists are referred to as convolutions, and it is believed that this corkscrew shape of the cotton fiber is important in spinning because of the natural interlocking of fibers in the yarn which results from such irregularity in fiber shape. Some varieties of cotton are found to have more convolutions than others, and very thin-walled fibers as well

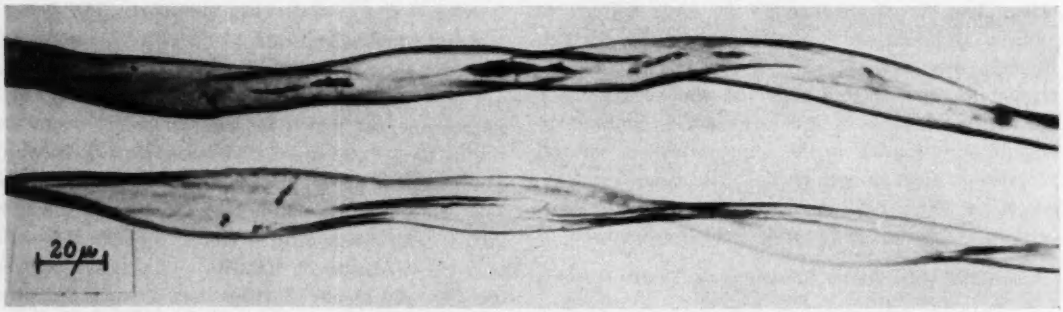


FIG. 1. *Longitudinal view of short lengths of cotton fibers showing typical convolutions: above—mature, below—immature.*

as very thick-walled fibers are almost devoid of these twists altogether. Figure 1 shows short lengths of two fibers photographed at high magnification to show details of the convolutions, the one at the top being normally developed, the one at the bottom a typical immature fiber. The cotton fiber is both colorless and transparent to transmitted light, so that the central canal or lumen and the thickened cell wall may be easily seen at the same time. The convoluted character is observed to vary from region to region of the same fiber, or from fiber to fiber in the same sample. Because of the inherent variability of cotton it has been estimated that a statistically representative sample for measurements of ribbon width or fiber diameter must contain not less than 300 fibers [8, 9]. The difference in cell-wall thickness between mature and immature fibers may best be seen in cross sections of bundles of fibers such as are shown in Figure 2.* The oval or "kidney-bean" shape of the normal, fully developed, thick-walled fibers at the left is contrasted with the contorted and curled sections at the right which result when underdeveloped, thin-walled fibers dry out and collapse. Their shapes are flatter than those of the fully matured fibers. There are always some immature fibers in every sample. In normal commercial cottons about one-fourth of the fibers are thin-walled.

* Figures 2, 3, 5, 8, 12–15 are also appearing in another article by Miss Rollins "Some Aspects of Microscopy in Cellulose Research" in the April issue of *Analytical Chemistry*.

Observations with Polarizing Microscope

By examining the fiber in its natural state with the polarizing microscope additional information may be gained from gross optical effects which are independent of any morphological feature but indicative of internal molecular structure. The optical anisotropy of fibers, observed with polarized light, arises from the ability of the individual structural units (glucose residues) to resolve light rays vectorially; when the structural units are ordered or oriented, the effect is superposed and enhanced. This double refraction of the cellulose molecules leads to the production of color effects when cellulose specimens are observed

Fig. 2. *Cross sections of cotton fibers: left—thick-walled, mature fibers, right—thin-walled, immature fibers.*

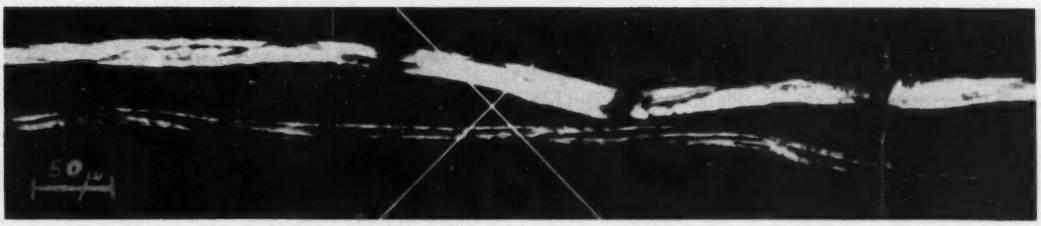


Fig. 3. *Mature and immature cotton fibers between crossed nicols.*

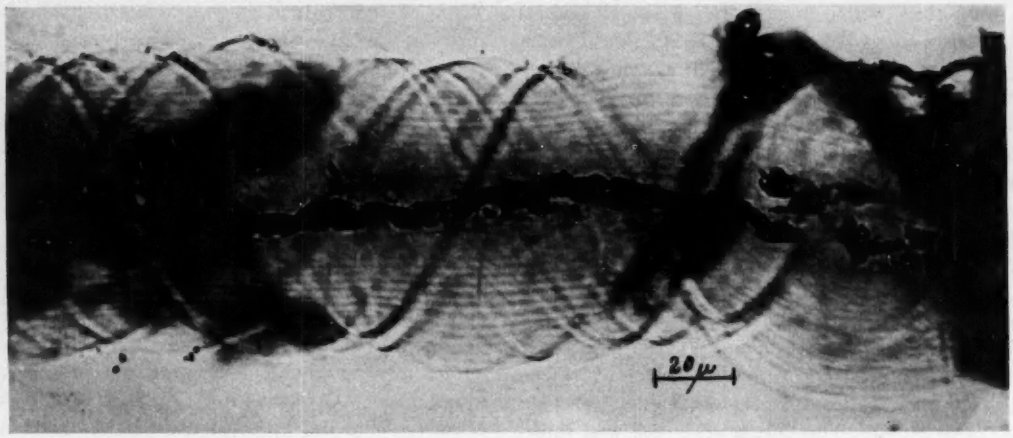


FIG. 4. *Cotton fiber stained to show primary wall and lumen and swelled in cupri-ethylenediamine.*

in polarized light, the color depending on the degree of retardation of the different wave lengths of light by the doubly refractive units within the specimen. By using additional selective retardation in the form of a selenite plate in the optical path, these colors may be changed and intensified. In specimens of the same thickness and substance, the brilliance of birefringence is interpreted as indicative of the degree of orientation; in specimens of the same orientation and same substance, the brilliance of birefringence is taken as indicative of thickness, thinner specimens being less bright. Because the cotton fiber is twisted, crumpled, and wrinkled due to the irregular collapse of its cellulosic tube, its polarization colors are the result of a complex combination of effects. However, the characteristically brilliant birefringence of the cotton fiber has been usefully interpreted as indicative of its highly oriented macromolecular structure. From refractive index measurements it is determined that birefringence is positive; this indicates that the majority of the chains within the cellulose structure lie more nearly parallel than normal to the fiber axis. From mathematical formulas based on optical considerations the angle of inclination with respect to the fiber axis can be calculated from the two refractive indices, to give for most cottons an angle of orientation in the neighborhood of 30° [13].

One of the simplest applications of polarized light microscopy is the A.S.T.M. [1] method for determining maturity in commercial samples of cotton, in which the criterion of cell-wall thickness is the amount of retardation of the light upon passing through the fiber. In Figure 3 one sees a thick-walled fiber (top) which, when placed in the proper position in the polarizing microscope, transmits a green or yellow color; below is a thin-walled fiber which appears blue under these conditions. This picture also illustrates an interesting phenomenon of crystallite orientation peculiar to cotton fibers. Although the microfibrils in cotton lie roughly parallel, they spiral around the axis in a helical manner as indicated both by the angle of inclination calculated from refractive indices and by x-ray diffraction measurements [14]. The direction of the helix is reversed many times along the length of the fiber and when the fiber is observed under the microscope in polarized light these points of reversal appear as dark extinction bands in the brilliantly birefringent fiber [6]. Osborne [12] has pointed out that these are the only places in the length of the fiber where the majority of fibrils lie actually parallel to the fiber axis; and that in each case the linear distance is very short. Wakeham [17] has concluded from statistical considerations of the frequency of rupture at reversal points that these regions are mechanically weaker than other regions along the main body of the fiber.

Observations by Swelling Techniques

None of the details of fiber architecture are visible in the raw, unswollen fiber; but swelling in appropriate dispersing agents, such as 70% sulphuric acid, cuprammonium hydroxide, or one of the other cupritetrammine bases, will reveal many of the inner structural features, especially if the fiber is also stained, as shown in Figure 4. Because of its pectic

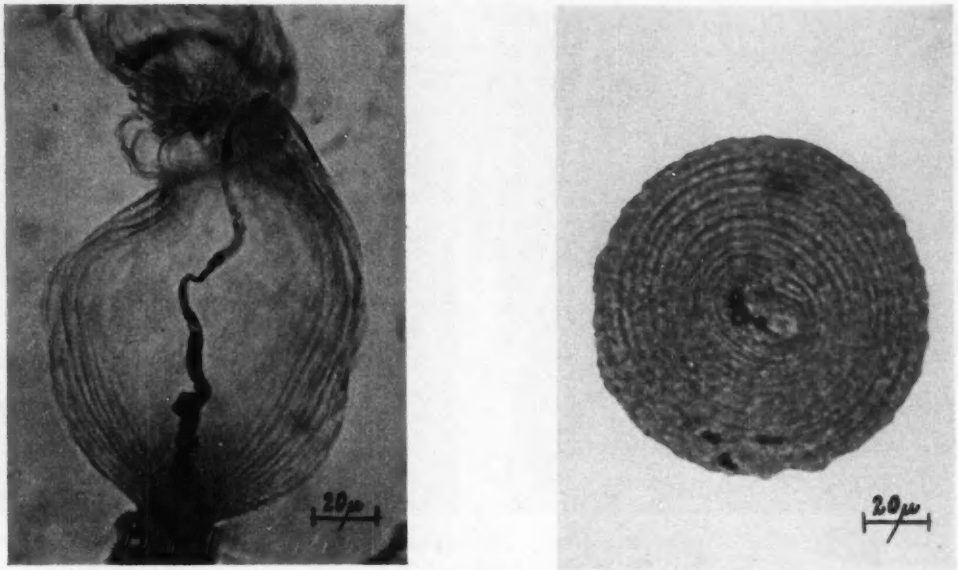


Fig. 5. *Swollen cotton fiber showing growth layers inside ballooned wall: left—longitudinal view, right—cross-sectional view.*

content the primary wall may be stained with ruthenium red, methylene blue, or Nile blue sulphate, the basic dyes reacting with the carboxyl groups present; these dyes also stain the proteinaceous lumen contents for the same reason. The wax complexes of the cuticle can be colored faintly with such fat stains as Sudan Black and oil red, but are more deeply dyed after the fibers have been briefly treated with hot ethyl alcohol [10, 16]. The primary wall is seen peeling off the outside of the "balloons" or clinging to the constricting collars between them, while the dark-stained lumen contents can be seen at the very center of the fiber. Just beneath the primary wall, but unstained, can be seen evidence of the colorless, coarse fibrils of the winding layer. At the left in Figure 5 the layers of the secondary wall can be plainly seen inside the balloon-like swelling, and at the right their concentric arrangement is obvious in a swollen cross section. Figure 6 illustrates in a schematic way the lamellate morphology of the cotton fiber as revealed by such conventional swelling studies with the light microscope, and now generally accepted by most workers [5]. The primary wall and cuticle together form a thin continuous membrane covering the entire fiber and enclosing the winding and other layers of secondary thickening which make up the bulk of the fiber. The lumen or

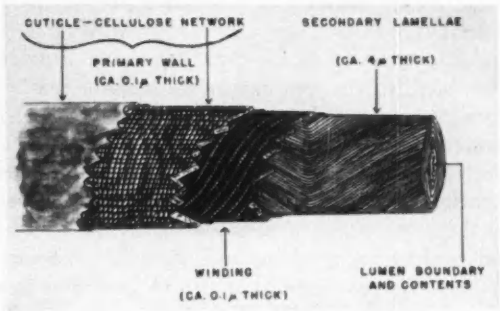


Fig. 6. *Schematic diagram of layered components of fiber cell wall.*

central canal contains the desiccated remains of the protoplasmic material which filled it during the growth period. Such, briefly, is the extent of our knowledge of the structural details of the cotton fiber in terms of what can be seen with the light microscope.

The Electron Microscope

The primary purpose of a microscope is to produce high magnification, and this is done by a combination of lenses. The compound microscope in the simplest sense is merely one in which double magni-

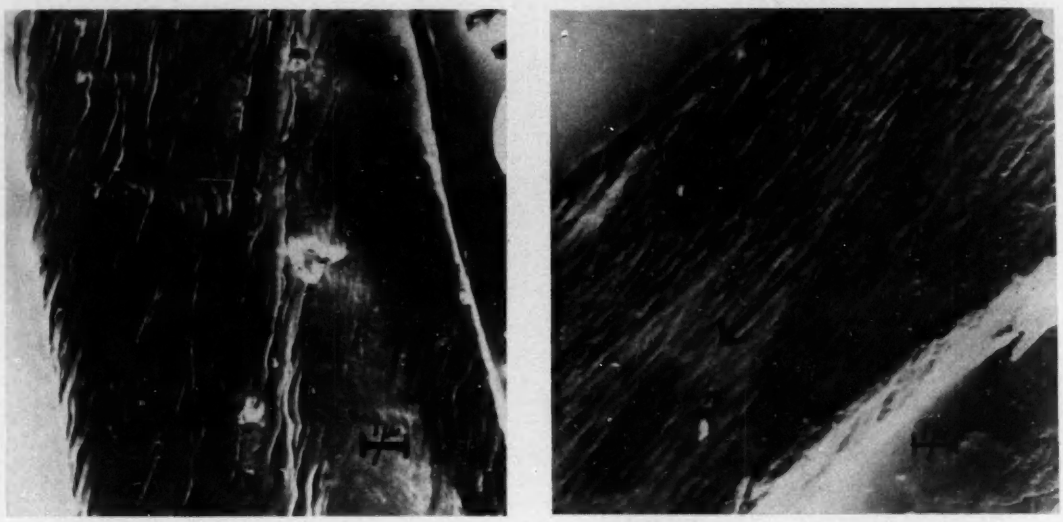


FIG. 7. *Surface replicas of cotton fibers: left—untreated, right—commercially mercerized. Arrow indicates direction of fiber axis.*

fication takes place: one lens gives a primary enlargement of the object under observation which is then further enlarged by a second lens. In the research type microscope a third system of lenses in the substage condenser is used between the lamp and the object stage to concentrate the beam of light and focus it onto the specimen. The objective, the lens nearest the object, produces an enlarged and inverted image of the object under observation; this image, which exists in space at the conjugate focus of the objective, is then picked up and still further enlarged by the eyepiece lens. Thus the microscope through its two systems of lenses performs three optical functions: (*1*) concentration of rays, (*2*) formation of an image, and (*3*) magnification. The result seen by the eye or photographed on a film is the magnified virtual image of a magnified real image of the object.

In the electron microscope the essential units are the same except that instead of a light source we have an electron beam source and the lenses are electromagnetic or electrostatic fields rather than refracting glasses. An optical lens focusses light by refracting it as it enters or leaves its surfaces; an electron lens bends or "persuades" the electron beam into a curved path during transit. The light microscope has a fixed set of possible magnifications depending on the combination of lenses and the length of the draw tube and projection distance; in the electron microscope increase in magnification is continuous throughout the passage of the beam through the lens which has no sudden boundaries. The effective focal length of an electron lens will be determined by the shape and intensity of its electric or magnetic fields. Similarly the focus will vary with the speed of the entrant electron beam. The primary advantage of the electron microscope is its high resolving power, and the fact that its lenses have continuously variable focal length over a wide range; its chief limitation lies in the poor penetration of matter by the electron beam so that only very thin specimens can be investigated, and these have to be desiccated before introduction into the vacuum.

Although it is not possible to examine a whole cotton fiber in the electron microscope because of the small area of view and the great thickness of the specimen, which is much too thick for penetration of the beam, details of surface topography may be studied by means of replica techniques. In one such technique a plastic cast is made of the fiber surface and this impression is subsequently reproduced in silica as a positive image. Finally, the silica cast is coated by vacuum evaporation with a deposit of some heavy metal which scatters electrons. The coating is usually applied at an angle in order to emphasize slight elevations and depressions in the specimen. This process of metal coating is called "shadowing" and the shadow-cast specimen when

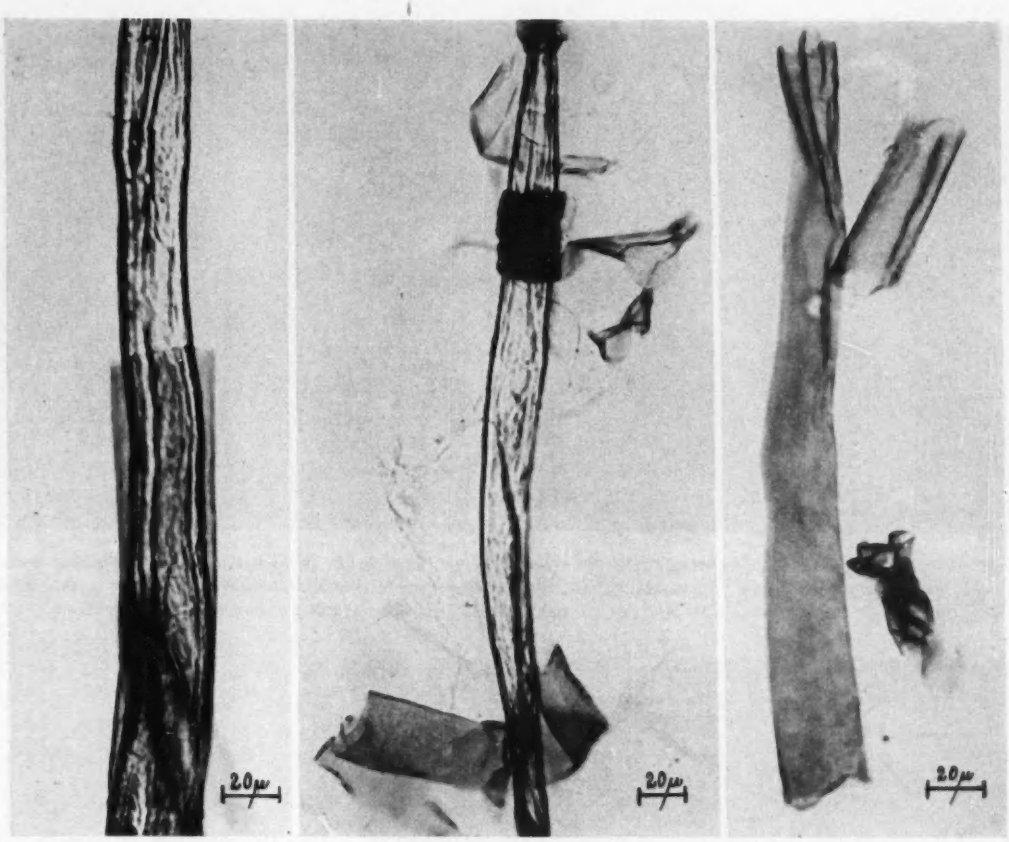


Fig. 8. *Primary wall peeling from fiber surface after beating in water in Waring Blendor* [16].

examined in the electron microscope shows greatly enhanced contrast. The shadow-cast silica image of the original plastic impression of the fiber surface shows fine details of surface topography which cannot be observed in any other way. In Figure 7 (left) is such a replica of the surface of a native cotton fiber showing wrinkles, grooves, and fissures which are characteristic of the fiber surface. That the swelling which accompanies the process of mercerization smooths out this roughness to some extent is evident in the picture at the right which is an electron micrograph of the replica of the surface of a fiber which has been mercerized under normal tension.

Observations on the Primary Wall

Because of the thickness of the normal fiber little else can be learned about it in its intact condition with the electron microscope. However, the layered arrangement of the fiber wall makes it possible, by means of mechanical beating, to isolate some of its morphological parts in a relatively undamaged condition for further study. Figure 8 shows the primary wall slipping off the intact fiber, after brief beating in water in a high speed Waring Blendor. These sleeves, when released from the fiber, expand to a width much greater than that of the fiber itself, probably approximating the size and shape of the primary wall in the growing state before shrinkage and desiccation created the wrinkled condition noted in the surface pictures in Figure 7. Under the optical microscope typical staining reactions and characteristically faint birefringence in polarized light aid in determining that the samples are free from contamination with other portions of the cell wall. By chemical analyses of such separated fractions it has been determined that the primary wall is approximately 54% cellulose, and that the noncellulosic

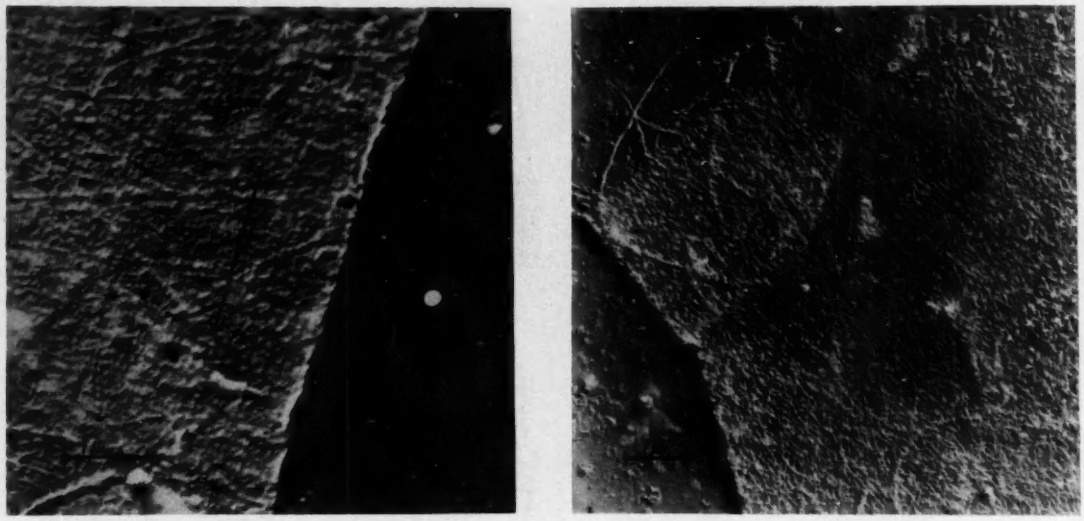
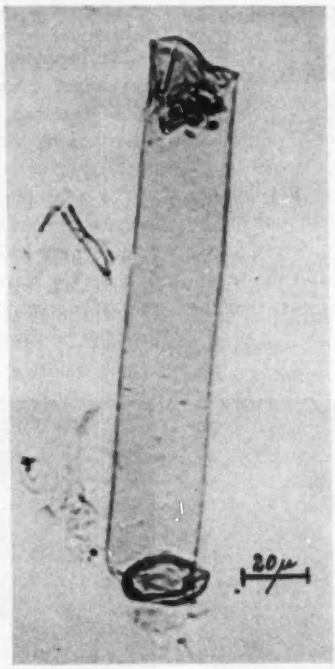


FIG. 9. *Electron micrographs of sleeves of primary wall: left—prior to removal of noncellulosic material, right—after purification by digestion with hot alkaline solution. Arrow indicates direction of fiber axis. Spheres are polystyrene latex particles used in electron microscopy as reference objects for purposes of calibration.*

FIG. 10. *Electron micrograph of primary wall after careful purification, showing two fibril systems. Arrow indicates direction of fiber axis. Spheres are polystyrene latex particles used in electron microscopy as reference objects for purposes of calibration.*

fraction is made up of pectic material, nitrogenous substances, waxes, and other unidentified substances.

In the electron microscope these raw primary wall specimens show little or no structure, but after extraction of the noncellulosic constituents with alcohol followed by ethanolamine, they have the interlaced arrangement of cellulosic fibrils shown by Mühlethaler [11] to be typical of primary walls in vegetable fibers. The interwoven or felted network structure is made up of fibrillar strands some 100 to 400 Å. in diameter. In Figure 9 the fragment at the left has received no treatment while the specimen at the right has been freed of noncellulosic encrusting materials. From examination of such fragments in the form of sleeves it has been learned that the complex of waxes, pectinaceous, and nitrogenous materials impregnates the cellulosic fabric more or less completely but exist in a thicker film on the outside of the wall than



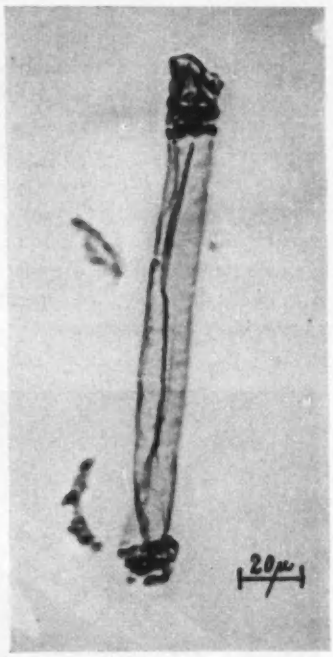
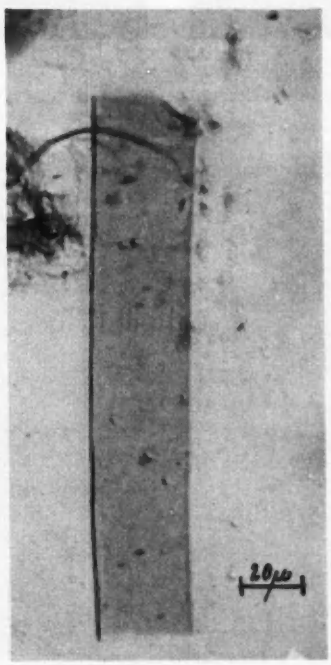


Fig. 11. *Unpurified sleeve of primary wall: left—in water, right —in 18% sodium hydroxide.*



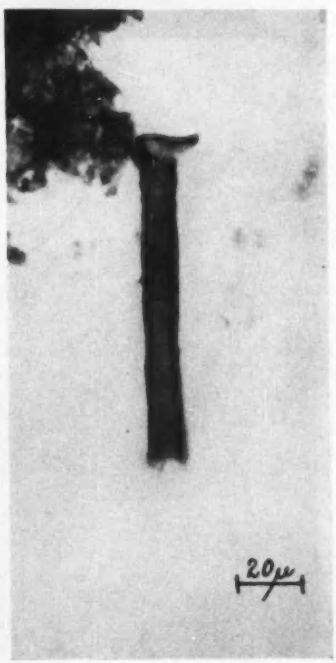


Fig. 12. *Sleeve of primary wall freed of noncellulosic substances: left—in water, right—in 18% sodium hydroxide.*

on the inside. It would appear that although in both surfaces the fibrils are interwoven at random, there is a general system of orientation which is axial on the outer surface of the sleeve and transverse on the inner surface. In Figure 10 which is an enlarged picture of a more carefully purified fragment of primary wall the two-system pattern of fibrillar arrangement is evident. The over-all structure of the primary wall may be likened to that of a woven fabric in which the axial fibrils are the warp and the transverse fibrils the filling. In general, it appears that the transverse system predominates.

Behavior of the Primary Wall on Mercerization

The behavior of the primary wall toward chemical treatments common to textile processing and cellulose research has been the subject of preliminary observations at the Southern Regional Research Laboratory.

For example, the behavior of the primary wall toward mercerizing strength caustic soda explains in some degree its restricting action on the free swelling of the fiber during mercerization. Mercerization itself apparently removes little of the noncellulosic material of the primary wall. It does, however, in-

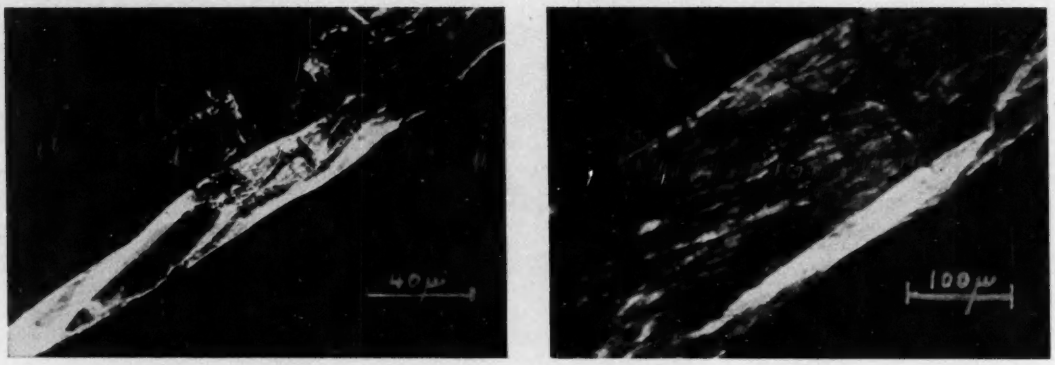


FIG. 13. *Short length of winding layer between crossed nicols: left—showing primary wall adhering, right—showing details of structure.*

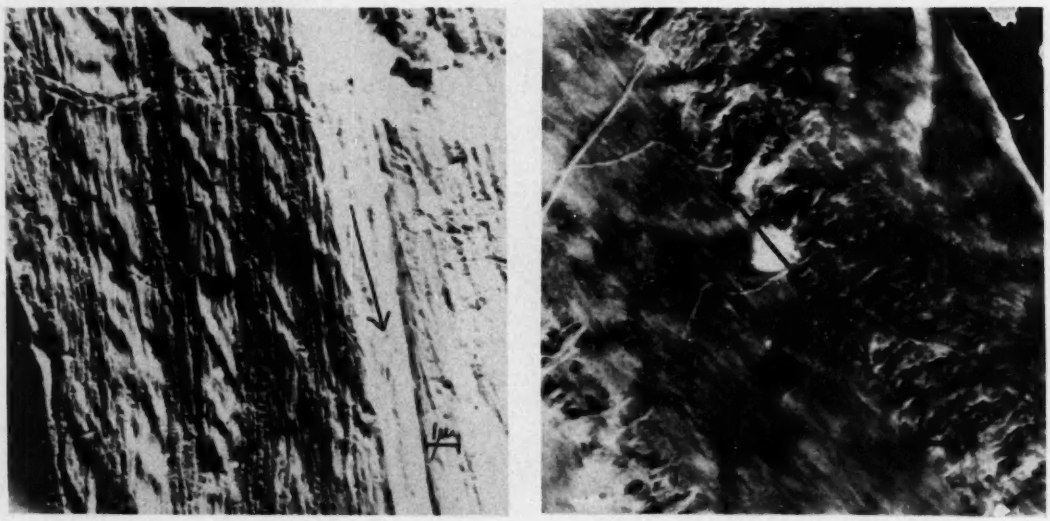


FIG. 14. *Electron micrographs of winding layer: left—unpurified winding from 17-day old fiber, right—purified winding from a fiber of unknown age. Arrow indicates direction of fiber axis* [16].

duce shrinkage of the network fabric in both directions. Figure 11 shows a sleeve of raw primary wall in water and in 18% sodium hydroxide; shrinkage in the lengthwise direction is only 3% but in the transverse direction approximately 30%. In Figure 12 are shown similar sleeves of primary wall material which have been extracted free of noncellulosic materials. The shrinkage in going from water to 18% sodium hydroxide is 40% in lengthwise direction and nearly 60% in crosswise direction. These observations help to account for the changes in shape and cross-sectional area of cotton fibers which occur as a result of mercerization.

As the surface which comes into immediate contact with processing environments the primary wall is significantly involved in frictional effects, wetting, dyeing, and similar phenomena of the manufacture and chemical finishing of cotton. For this reason, even though it constitutes but 3% of the bulk of the fiber, the nature and behavior of this thin membrane are important since all reagents must pass through the primary wall to reach the body of the fiber.

Observations on the Secondary Wall

Immediately beneath the primary wall lies the first layer of secondary thickening called the "winding layer" by Hock [6] because of its characteristic behavior in swelling reactions. This first layer of secondary wall has recently been isolated from untreated, native cotton fibers by beating briefly in a Waring Blendor fibers which were taken from 17-day old bolls. Figure 13 shows a specimen under the light microscope. It can readily be distinguished from the primary wall fragments which cling to it by its failure to stain with any of the reagents which color noncellulosic materials and by its higher birefringence in polarized light. The winding layer appears to be composed of a single layer of fibril bundles oriented at an angle to the fiber axis. In certain regions the reversal of direction of some of the fibril bundles could be observed.

Electron microscope observations of such specimens are presented in Figure 14 which shows, at the left, winding layer taken from a 17-day old fiber, and at the right a specimen of purified winding layer from a fiber of unknown age, presumably more mature. The banded pattern observed in the light microscope is revealed by the electron microscope to have a complex structure of alternating bands of closely aligned and of openly woven fibril bundles. It is obvious that little difference exists between the more mature purified specimen and that from the raw 17-day old fiber. Under the light microscope the winding layer gives the typical staining reactions of cellulose, and no indication of noncellulosic content has as yet been demonstrated. However, in the dissolution of chemically modified fibers there is repeated evidence of the winding layer as an undissolved residue, possibly indicating nonreacted material. A helical tape structure has often been noted in swollen fibers, as in Figure 4, and is frequently referred to in the literature, especially that dealing with cellulose derivatives. The failure of the winding layer to become completely soluble when chemically substituted cotton fibers are immersed in the appropriate solvents may be explained on the basis of the effect of physical structure on the modification reaction. In the course of these chemical reactions there is usually enormous swelling of the secondary wall, and the winding layer, at the outer area of the fiber, is thus put under considerable tension by the enlargement of the cellulose cylinder beneath it. Sisson [15] has pointed out that cellulose under tension tends to resist intramicellar swelling; thus the degree of substitution of the winding layers may be somewhat less in any given length of reaction time than that of the rest of the secondary wall. In solvents which dissolve the more fully substituted cellulose of the main body of the fiber, the winding layer persists as a slowly soluble skeleton.

Fig. 15. *Electron micrograph of secondary wall cellulose from main body of the cotton fiber.*

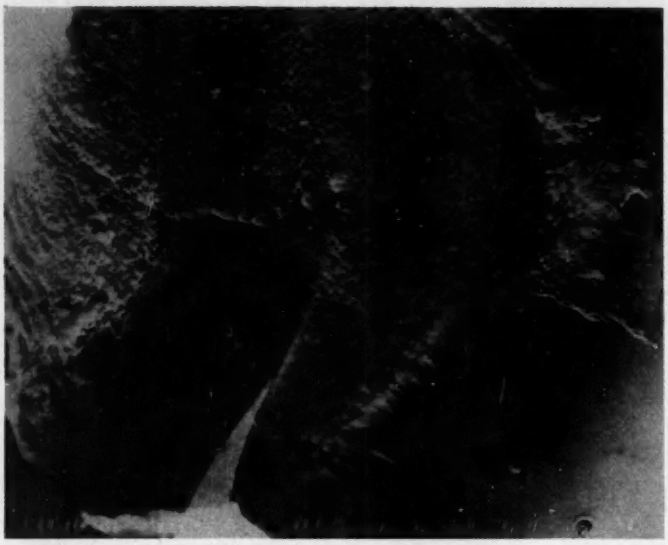


FIG. 16. *Electron micrograph of ultra-thin cross section of unswollen cotton fiber.*

To date no separate sleeves have been successfully isolated from the main body of the secondary wall. From specimens beaten in the Waring Blendor it has been possible to isolate for electron microscope study samples which, from their brilliant birefringence in polarized light, are confirmed to be secondary wall, and which are beaten thin enough to be penetrated by the electron beam. Figure 15 shows a view of such a fragment. It is in agreement with similar pictures in the literature for secondary wall cellulose from flax, ramie, and wood pulp fibers [18], and is believed to represent the normal structure of the main body of the cellulose fiber. The fibrils are closely appressed in a strongly parallel system which appears to be more or less continuous. There is no regular pattern of interruption as in the banded structure of the winding layer or of weaving as in the network structure of the primary wall. In Figure 16, an electron micrograph of an unswollen cross section of a cotton fiber, little detail of wall structure is seen even at a magnification of 12,000 diameters.

These preliminary observations on the architectural elements of the cotton fiber serve to illustrate the nature of the voids in our understanding of the structure and behavior of cotton as a textile material. While much progress has been made in the adaptation of the natural fibers to modern requirements, it is probable that faster progress can be made in the field of chemical modification when procedures become less empirical and more nearly governed by basic knowledge of the fundamental nature of the problem. To this end light microscopy and electron microscopy must be used together with other physical and chemical tools of modern technological investigation.

Acknowledgment

The electron microscope was used through the courtesy of the Tulane University Biophysics Department and Charity Hospital, New Orleans, Louisiana.

Literature Cited

1. ASTM Standards on Textile Materials, 307–8 (1950).
2. Anderson, D. B., and Kerr, T., Growth and Structure of Cotton Fiber, *Ind. Eng. Chem.* **30**, 48–54 (1938).
3. Balls, W. L., The Determiners of Cellulose Structure as Seen in the Cell-Wall of Cotton Hairs, *Proc. Roy. Society (London)* **B95**, 72–89 (1923).
4. Cotton Situation CS-139, *U. S. Dept. Agr. Bur. Agr. Econ.*, Jan.–Mar. (1953).
5. Flint, E. A., The Structure and Development of the Cotton Fiber, *Biol. Revs. Cambridge Phil. Soc.* **25**, 414–34 (1950).
6. Hock, C. W., Ramsay, R. C., and Harris, M., Microscopic Structure of the Cotton Fiber, *J. Res. Natl. Bur. Standards* **26**, 93–104 (1941).
7. Kerr, T., The Outer Wall of the Cotton Fiber and Its Influence on Fiber Properties, TEXTILE RESEARCH JOURNAL **16**, 249–54 (1946).
8. Koshal, R. S., and Turner, J. A., Studies in the Sampling of Cotton for the Determination of Fibre-Properties, I, II, *J. Textile Inst.* **21**, T325–70 (1930).

9. Koshal, R. S., and Turner, J. A., Studies in the Sampling of Cotton for the Determination of Fibre-Properties, III, *J. Textile Inst.* **22**, T17–55 (1931).
10. Moore, A. T., Stains for the Primary Wall of the Cotton Fiber, *Stain Technol.* **28**, 149–54 (1953).
11. Mühlethaler, K., Electron Micrographs of Plant Fibers, *Biochim. et Biophys. Acta* **3**, 15–25 (1949).
12. Osborne, G. G., Micro-Analysis of Textile Fibers, III, TEXTILE RESEARCH **5**, 275–97 (1935).
13. Preston, J. M., "Modern Textile Microscopy," London, Emmott & Co. Ltd., 1933.
14. Sisson, W. A., Identification of Crystalline Cellulose in Young Cotton Fibers by X-Ray Diffraction Analysis, *Contribs. Boyce Thompson Inst.* **8**, 389–400 (1937).
15. Sisson, W. A., "Cellulose and Cellulose Derivatives" (E. Ott, editor), New York, Interscience Publishers, Inc., 1943, pp. 277–78.
16. Tripp, V. W., and Rollins, M. L., Morphology and Chemical Composition of Certain Components of Cotton Fiber Cell Wall, *Anal. Chem.* **24**, 1721–8 (1952).
17. Wakeham, H., and Spicer, N., The Strength and Weakness of Cotton Fibers, TEXTILE RESEARCH JOURNAL **21**, 187–94 (1951).
18. Wyckoff, R. W. G., "Electron Microscopy," New York, Interscience Publishers, Inc., 1949.

The Production and Properties of Solution-Dyed Acetate*

Paul F. Flamm†

THE INTRODUCTION of solution-dyed acetate to the trade has opened up new applications for acetate fibers and overcome some of the disadvantages of acetate fibers dyed in the conventional manner. Solution-dyed acetate can be considered a new fiber from the standpoint of the fabric designer. It certainly has received enthusiastic acceptance by the trade and consumers. Because of the way it is made and the special coloring agents used, it has all-around colorfastness qualities never before achieved by any other type of textile fiber, either natural or man-made. Its unique properties are being used to advantage for apparel and home furnishings.

Over a decade ago Tennessee Eastman Company carried out considerable research and development work on solution-dyed acetate fibers. At first, the earth pigments, such as iron oxides, were used because of their relative stability and low cost. However, along with this stability it was found that acetate yarns containing these pigments were highly abrasive in addition to exhibiting low luster. Only colors of low saturation could be produced, and pastels were practically out of the question.

The first solution-dyed acetate yarn appeared on the market just before the second World War. Black solution-dyed acetate was used successfully in the manufacture of neckerchiefs and neckties for the Navy. The neckerchiefs could be washed and worn without fear of the black pigment rubbing off on the white Navy blouses. The success of black solution-dyed acetate renewed interest in the possibilities of other colors. After World War II research and development was intensified to such an extent that several colors were available to the trade early in 1948.

From the modest beginning of several thousand pounds of black yarn in 1940 the production of solution-dyed acetate has expanded to many millions of pounds in 1953. A wide range of colors is now available.

The purpose of this paper is to describe this product, its manufacture, and its uses. This information will include the selection of coloring agents, their incorporation into the spinning solution, their evaluation, and their control. The discussion will also include the physical and chemical properties and some of the important end uses of the product.

Production

Solution-dyed acetate is dry-spun from colored solutions of cellulose acetate, using conventional techniques.

For those who are not familiar with the acetate spinning process, a brief description is probably

* Presented at the Annual Meeting of Textile Research Institute in New York City, Nov. 12, 1953.

† Superintendent, Acetate Staple Division, Quality Control Department, Tennessee Eastman Co., Kingsport, Tennessee (Division of Eastman Kodak Company).

in order. The cellulose acetate spinning solution is forced through the spinnerette, containing very small holes, into a stream of warm air. The warm air evaporates the solvent and leaves filaments of cellulose acetate. These are either wound on bobbins as continuous filament yarn or gathered into a tow and cut into short lengths known as staple fiber.

In the manufacture of solution-dyed acetate, the coloring agent is dispersed in the spinning solution. The filaments formed by the evaporation of the solvent contain the coloring agent uniformly distributed throughout each filament. Cross-sectional photomicrographs demonstrate the difference between this fiber and an acetate fiber dyed in the normal manner. The latter fiber shows color only on the surface.

Incorporation of Coloring Agents

To utilize the maximum color efficiency of a particular coloring agent it must be properly dispersed in the spinning solution. This is probably the most important process in the manufacture of solution-dyed acetate.

Poor dispersion results in low color efficiency and also impairs physical properties of the yarn. Large particles reduce yarn tenacity and elongation very noticeably and result in excessive pigment usage to develop the desired hue. There are many well-known methods of dispersion, and no attempt will be made to discuss these in detail or to express an opinion as to the best method.

Each producer has his special process for incorporating coloring agents into the spinning solution. However, all processes are designed to give the same result—a product uniform in color. Among the conditions met by the various processes in arriving at this goal are the following:

(*1*) The filament denier is maintained within very close tolerances. The effect of variations in filament denier on yarn color is very pronounced. As a rule, in yarn from a given spinning solution, the lower the filament denier the lighter the color. For example, a 20 den. per filament fiber spun from the same solution used to spin a 4 den. per filament Navy Blue fiber appears almost black.

(*2*) The homogeneity of the solution is maintained by careful control of factors influencing filtration.

(*3*) The ratio of coloring agent to cellulose acetate is controlled very closely.

Choice of Coloring Agents

Before discussing color control and color tolerances, some of the interesting aspects of the choice of coloring agents will be considered.

The proper choice of coloring agents is of paramount importance in the manufacture of a high-quality, solution-dyed acetate yarn. The physical and chemical properties of the coloring agents used determine the properties of the resulting yarn, especially with respect to fastness properties.

Hundreds of inorganic pigments, organic pigments, and dyestuffs have been screened in the search for suitable coloring agents for solution-dyed acetate. There are a number of excellent coloring agents which have no dye affinity for acetate yarn but which show excellent fastness properties when used in solution-dyed acetate.

In choosing a coloring agent for use in solution-dyed acetate, there are certain fundamental physical properties which must be considered. Most important are the absorption, reflection, transmission, and scattering characteristics of the coloring agent. The change of refractive index with wavelength between 400 and 700 mμ is useful in predicting the performance of a particular coloring agent in cellulose acetate yarns. The coloring agent must also be stable to light, atmospheric fumes, heat, perspiration, washing, dry cleaning, acids, and alkalies. The ultimate particle size, shape, and ease of dispersion are very important too.

Evaluation of Coloring Agents

Before a coloring agent is approved for use in the manufacture of solution-dyed acetate, it must pass certain tests and meet certain standards.

If a coloring agent appears promising, it is dispersed in a cellulose acetate solution from which a small sample of yarn is spun. The hue, saturation, and brightness of this sample are then judged both visually and spectrophotometrically. The sample is then subjected to various fastness tests, among which are the following:

Light.—Exposure in the Atlas Fade-Ometer and in sunlight. These tests are carried out according to standard procedures set forth in AATCC tentative test methods Nos. 16A-52 and 16B-52. The samples are exposed until "just appreciable fading" is noticed.

There is usually fairly good correlation between Fade-Ometer and sunlight exposures, but sometimes the difference is quite pronounced. The exposure to sunlight is less constant because of the variation in

the energy absorbed by the test panel due to the varying angle at which light strikes the panel and also to the interference of clouds and dust.

Laundering.—Treatment in the Atlas Launder-Ometer according to AATCC tentative test method No. 36–52.

Atmospheric fumes.—AATCC tentative test method No. 23–52.

Perspiration.—AATCC tentative test method No. 15–52.

Crocking (wet and dry).—AATCC tentative test method No. 8–52.

Acids and alkalies.—AATCC standard test method No. 6–52.

Dry cleaning.—AATCC tentative test method No. 25–52.

Weathering.—Exposure in the Weather-Ometer.

Some other tests which are made on the prospective coloring agent are:

Corrosion.—The effect of the coloring agent on the metals used in the processing equipment is determined. The effect of various metals on the color of the coloring agent is also investigated.

Dispersion.—A coloring agent may have all the desired fastness properties, but if it cannot be dispersed readily it is undesirable.

Ultimate particle size.—Coloring agents from different sources may vary in ultimate particle size and usually the smallest particle is the most desirable.

Abrasion.—An abrasive coloring agent is undesirable.

Usually the above tests are repeated a number of times to establish the level of quality of the coloring agent before approval for use in production.

Color Control

The importance of adequate color control is quite apparent when it is considered that the color tolerances required for some applications of solution-dyed acetate are critical.

Let us consider one application which will illustrate this point. One of the most critical applications of solution-dyed acetate is in solid-color, loom-finished taffetas for evening dresses. In this fabric, the warp may contain ends from different shipments of yarn and yet the fabric must be free of warp streaks. It is obvious that if there is a noticeable difference in color of the various warp ends, the fabric would be unsatisfactory. The fact that the yarns are parallel and in close proximity is the reason that small color differences are so noticeable. Very few colored products require such close color tolerances.

A dress manufacturer would not think of making half of an evening gown from one dye lot of cloth and the other half from another dye lot. He knows that the control of dye baths is not precise enough to dye two bolts of cloth exactly the same color.

Other methods of dyeing are unable to obtain the color uniformity which has been achieved with solution-dyed acetate. A satisfactory piece of cloth can be made from solution-dyed acetate even though the warp may contain yarn from several different shipments.

The scientific application of such basic principles as additive and subtractive color-mixture theory is very useful in making the adjustments necessary to keep a particular color on standard day-in and day-out. It is not within the scope of this paper to discuss in detail the many methods used to maintain color uniformity. However, the two general methods available for evaluating color uniformity from raw materials to the finished product will be described briefly. These are instrument control and visual control.

Instrument control.—Various color-measuring instruments are employed as supplemental aids to visual methods in controlling color in the manufacture of solution-dyed acetate. There are many colorimeters and spectrophotometers on the market which are useful in determining color differences and establishing standards. Among instruments which may be used in various stages of the process are the General Electric Spectrophotometer with Automatic Integrator, the Instrument Development Laboratories "Color-Eye," the "Colormaster" Differential Colorimeter, the Hunter Color-Difference Meter, the Beckman "DU" Spectrophotometer, and the Coleman Junior Spectrophotometer.

Most color-measuring instruments are limited in the accuracy of reflectance measurements because of the difficulty in preparing suitable samples for presentation to them. Transmittance measurements of high accuracy and precision can be made with most of the instruments listed.

The difficulty in obtaining accurate reflectance measurements also restricts the use of the CIE system for specifying the color and color tolerances of a particular solution-dyed acetate yarn. At the present time, most customers prefer that the producer furnish them with a sample of the particular shade of solution-dyed acetate yarn to be matched by future shipments.

Visual control.—Final color approval for a shipment of solution-dyed acetate is generally accomplished by visual examination under a standard Mac-

beth light. The product must be not only uniform but also within very narrow tolerances when compared with the standard for that particular color.

There are two main reasons for the fact that final approval for color is made visually: first, the mill buying the yarn and the ultimate consumer usually judge the color visually; and second, the human eye is a highly sensitive mechanism which can discern smaller color differences than most instruments available today. The average color-matcher is also able to compensate for such factors as luster differences. Of course, the eye is subject to fatigue, and this fact must be taken into consideration when grading colors.

Other Factors Which Influence Color Uniformity

There are many factors, in addition to the basic color of the yarn, which influence the color uniformity of solution-dyed acetate fabrics. Some of these are:

Luster.—Yarn luster must be controlled closely because this affects the apparent yarn color.

Twist.—Twist must be closely controlled in order to avoid streaks.

Finishes.—Variations in color of lubricants and sizes can affect the appearance of a piece of cloth considerably.

Stretching.—Overstretching can affect the color by reducing the filament denier and thus lightening the color of the yarn.

Geometric spacing.—Spacing of the yarn ends in the warp must be controlled to minimize streaks.

Properties

Tennessee Eastman Company's solution-dyed acetate yarn and staple are known as CHROMSPUN. These products have many outstanding properties. CHROMSPUN is known especially for its all-around colorfastness characteristics. It exhibits excellent fastness to sunlight, washing, atmospheric fumes, perspiration, crocking, and dry cleaning. It also withstands other fading hazards such as salt water and the chlorine in swimming pools. It is slow to soil, easy to clean, quick to dry, and immune to moths and mildew. It also sheds wrinkles easily, resists shrinking, and has unexcelled draping qualities.

The tenacity and elongation of solution-dyed acetate yarn, in general, are slightly below the accepted values for bright acetate yarn. As a rule, the lighter the color the stronger the yarn.

The sticking point and melting point of solution-dyed acetate are 400°F and 500°F, respectively. The same precautions used in ironing other acetate fabrics should be observed for solution-dyed acetate fabrics.

The excellent lightfastness of solution-dyed acetate has permitted its use in fields previously closed to dyed acetate fabrics. Even better lightfastness may be expected as development of this relatively new product continues.

The washfastness of solution-dyed acetate is excellent, as determined by the No. 3 and No. 4 AATCC wash tests. However, strongly alkaline solutions should be avoided in home or commercial laundering.

Another outstanding property of solution-dyed acetate is its excellent fastness to atmospheric fumes. The AATCC test method No. 23–52 is used to evaluate this property.

Precautions must be taken in handling fabrics containing solution-dyed acetate in blends or combinations with other fibers. It must be remembered that this fiber is basically cellulose acetate and reacts to various chemical agents in the same way as regular acetate fibers. For example, solution-dyed acetate should not be used in fabrics which are to be vat-dyed. The coloring agents are stable, but the action of the alkali necessary for the reduction of the vat dyes causes enough surface saponification on the solution-dyed acetate to cause it to dye.

It would be impossible to cover all combinations of fibers which might be used in blends with solution-dyed acetate and all conditions which are encountered in the treatment of these fabrics. However, results of the following miscellaneous tests made on solution-dyed acetate will serve as a guide in the proper handling of fabrics containing this fiber:

Permanganate bleaching.—Solution-dyed acetate is fast to permanganate bleaching as carried out on woolens (treated with 2% solution of potassium permanganate for 30 minutes at 80°F).

Chlorine or peroxide bleaching.—Solution-dyed acetate is fast to chlorine or peroxide bleaching as performed on viscose or cotton fabrics (1 hour exposure in solution containing 0.3% available chlorine at 80°F; 7 hours exposure in alkaline peroxide bleach at 190°F).

Cross-dyeing.—Solution-dyed acetate withstands neutral cross-dyeing with viscose, cotton, and nylon. However, care should be exercised in using some solution-dyed fibers in woolen fabrics to be piece-

dyed. Some colors are not fast in the presence of the amounts of acid normally necessary to dye wool with acid dyes.

Stripping.—The stripping procedure commonly used to remove direct dyes from cotton or viscose and acetate dyes from cellulose acetate (10% sodium formaldehyde sulfoxylate and 5% formic acid for 45 minutes at boil) destroys or discolors some solution-dyed acetate colors. Sodium hydrosulfite should be avoided.

Enzyme desizing.—Solution-dyed acetate can be desized with standard enzyme desizing techniques without harmful effects.

Uses

The all-around fastness properties of solution-dyed acetate, added to the other properties which make cellulose acetate such a useful fiber, give it much wider application than conventionally dyed acetate. It is being used to make such apparel as suits, slacks, dresses, swimwear, sport shirts, rainwear, blouses, and piece goods. It is also used to advantage in such home furnishings as draperies, curtains, bedspreads, comforters, lampshades, and pillow cases. Other outlets include umbrella fabrics, flock, and decorative tape.

These applications are indicative of the wide variety of uses for this new fiber. The list of users and uses for solution-dyed acetate is steadily expanding.

Summary

Solution-dyed acetate is dry-spun from solutions containing highly dispersed coloring agents. The coloring agent is dispersed uniformly throughout each filament, whereas by standard dyeing techniques the coloring agent is confined to the surface.

Proper dispersion of the coloring agent is highly important. Poor dispersion lowers the color efficiency and impairs the physical properties of the yarn.

Uniformity in colors is achieved by controlling filament denier, homogeneity of the spinning solution, and ratio of coloring agent to acetate. Some other factors which influence color uniformity are luster, twist, finish, stretching, and the geometric spacing in the fabric. Color is judged by instrumentation and by visual means.

Coloring agents are selected on the basis of their optical, physical, and chemical properties. They must be stable under the conditions encountered by the fabric in service and in cleaning.

Solution-dyed acetate is considered a new fiber because of its unique all-around fastness properties, which complement the well-known inherent properties of cellulose acetate fibers. With the range of colors now available this fiber gives fabric designers unlimited pattern possibilities and color combinations never possible before the advent of this new product. Solution-dyed acetate has become established as one of the most useful of the man-made fibers.

The Complementary Nature of Fibers from Natural and from Synthetic Polymers*

J. B. Quig and R. W. Dennison†

Introduction

The degree to which man-made fibers will continue to grow and to prosper is dependent upon the successful utilization of their inherent chemical and physical characteristics and flexibility of form in products of ever-widening consumer appeal.

Today's textiles are made of thirty-odd natural and manufactured fibers. The textile technologist has learned to know the natural fibers by generations of inherited, and years of first-hand experience. His knowledge is based on a subtle blend of direct sensory impressions and the results of routine test methods, many of which are rather empirical. The scientist, stimulated to investigate all textile fibers by the acceptance of his own inventions—fibers, plastics, and synthetic rubbers, which he groups along

* Presented at the Annual Meeting of the Textile Research Institute in New York City, Nov. 12, 1953.

† Textile Research Division, E. I. du Pont de Nemours & Co., Inc.

with natural fibers and rubber under the general term "high polymers"—has made great progress in understanding the molecular architecture of these materials and in explaining their mechanical behavior in the terms of the strength of chemical bonds and other cohesive forces between the atoms and molecules.

The textile technologist now has the opportunity and the responsibility of bringing the scientific knowledge about new fibers down to earth in order that the textile industry and the consumer may profitably use such knowledge.

Each fiber has some property or combination of properties which is unique. Each fiber should be used alone or in combination with other fibers where its unique characteristics give it the best chance to contribute to fabric performance. The fabric manufacturer must define what properties he wants in a particular fabric; then he must select the proper fiber or combination of fibers, design, and develop a satisfactory product through experimental blending, treatment, and finishing.

In this quest for better fabrics, for wearing and house furnishings, it is axiomatic that the consumer wants functionality; that is, he wants resistance to wrinkling, retention of shape and crease, and dimensional stability. But he does not desire to secure functionality by making a serious compromise with aesthetic properties—style, appearance, handle, and draping qualities.

A solid premise for blending the various fibers stems from the fact that the thermoplasticity and relative water insensitivity of the new fibers made from synthetic polymers contribute in large measure to their important functional properties. On the other hand, the water sensitivity, dye acceptance, and other desirable properties of fibers from natural polymers contribute to their functionality. While there are definite advantages, for example, resulting from sensitivity to water and from thermoplasticity, there are also definite disadvantages. An important reason, then, for blending is the negation or absorption of any disadvantages peculiar either to natural or synthesized fibers. Furthermore, the versatility of function and design obtained by blending of fibers possessing diverse characteristics is certain to have a stimulating effect on the business of the textile industry.

The principal task facing the industry today is to bring functionality and aesthetic properties together and to set up some sign-posts that will point the way to the manufacture of better fabrics.

The objective of this paper is to demonstrate the complementary nature of the natural fibers and the fibers made from synthetic polymers. Thus it will be shown that the new fibers confer new properties and enhanced functional properties on the natural fibers and also on rayon and acetate; and, conversely, that the natural fibers and the man-made fibers, rayon and acetate, are adjunctive to the new fibers and likewise confer desirable properties on the new fibers.

In a discussion of this work, it is emphasized that there is no simple prescription for the blending of textile fibers and that the results reported are based on the particular fabrics examined. The emphasis is placed on the performance illustrated by these particular fabrics and on indications as to how desired fabric characteristics may be achieved in blended fabrics. It is recognized that yarn, fabric structure, and finishing operations greatly modify the nature of the blend and sometimes may be as important as fiber composition. Experience has shown, nevertheless, that the results of the particular blending experiments, reported herein, have been useful to textile technologists from the standpoint of indicating approximate fiber concentration ranges to be explored in their search for improved fabrics.

This paper summarizes data obtained by the Du Pont Textile Research Division. Some of the earlier data were published [3, 9]. Similar work in this field has been persued by Bogaty and coworkers at the Harris Research Laboratories [2].

Fabric Design and Construction

For most of the experimental fabrics of this study, nylon staple, Dacron polyester staple or Orlon acrylic staple have been combined into two component blends with rayon, acetate, or wool fibers and then woven into carefully controlled fabric constructions. The wool used was approximately 58's in the heavy fabrics and 64's in the light fabrics, and the man-made fibers were each 3 den. per filament staple cut to 2½ in. in length for the blends with wool and 2 in. in length for blends of all man-made. The constructions were either a heavy weight suiting patterned after a U. S. Quartermaster 18-oz. serge (specification MIL–C–823) or a plain weave tropical weight (*ca.* 6 oz./yd.^{2}) suiting. The yarns for any set of fabrics were spun to equal diameters rather than to the same count. They were given the same singles and plied twist. The weave was adjusted to the same pick and end count and the finishing was

identical. A series of tests was made with fabrics having slightly different constructions and somewhat modified finishing treatments, to gain assurance that minor variations had no appreciable effect on the results.

The same procedure, in general, was followed in the preparation and testing of blends of cotton with the synthesized fibers. For these blends, fabric constructions were selected to reproduce large volume cotton fabrics in the field of knitwear, denim, broadcloth, duck, and percale. For these blends with cotton, the synthesized fibers were used in the form of 1½ den. per filament, 1½ in. length staple.

For each phase of this work, all samples of a given fiber were taken from the same lot. The 58's wool was obtained from a leading manufacturer of 18-oz. wool serge for the Army Quartermaster and was certified as the same as wool used in acceptable Quartermaster fabric. The 64's wool was obtained from a leading manufacturer of fine wool suitings. The man-made and the synthesized fibers, all obtained from Du Pont production, were rayon Type C–4, acetate staple,* Dacron Type 5400 polyester fiber, Orlon Type 41 acrylic fiber and nylon Type 200.

Experimental Results

The general procedure has been to measure the values of a definite fabric performance characteristic for a set of fabrics varying in composition from a control fabric of 100% of a natural fiber through three or four blends, increasing the synthesized staple and finally a control fabric of the synthesized fiber. These data were then plotted as a function of fiber composition, usually with the fabric of 100% natural fiber at the left and 100% synthesized fiber at the right.

Fabric Strength

Two measures of strength were obtained; namely, tongue tear and tensile strength. Both were made with an Instron automatic recording tensile tester, following procedures of A.S.T.M. method D–39–49. The tongue tear strength was determined as the average force required to propagate a tear previously started in a fabric sample. The tensile strength was taken as the force required to break a sample ravelled to 1 in. in width with an initial clamp separation of 3 in. Samples in each case were conditioned in an atmosphere of 65% R.H. and 70° F.

* Not now produced by Du Pont.

Additions of either Dacron polyester fiber or nylon to rayon, wool, acetate, or cotton increased the tear strength in every case. Orlon increased tear strength somewhat when blended with acetate or wool.

These results are partially illustrated in Figure 1, in which fabric tear strength is plotted *versus* fiber composition, in this case, rayon and the three synthesized fibers. Tear strengths of rayon/synthetic blended fabrics appear to be greater than that of 100% rayon for all concentrations of nylon or Dacron, but slightly decreased for inclusions of Orlon. Similar results were obtained for blends of these synthesized fibers with wool, cotton, or with acetate—except, in the last case, the inclusion of Orlon at all concentrations slightly increased the tear strength over that for 100% acetate.

Tensile strength, on the other hand, was changed in a different manner for some fiber combinations. Figure 2 shows that for rayon/synthesized fiber blends the fabric tensile strength was increased with increasing Dacron or nylon only at concentrations above about 50% and was actually decreased by additions of less than 50% of these stronger fibers to rayon. Orlon staple slightly decreased the strength of fabrics when blended with rayon or cotton. However, the latter blended fabrics are stronger than

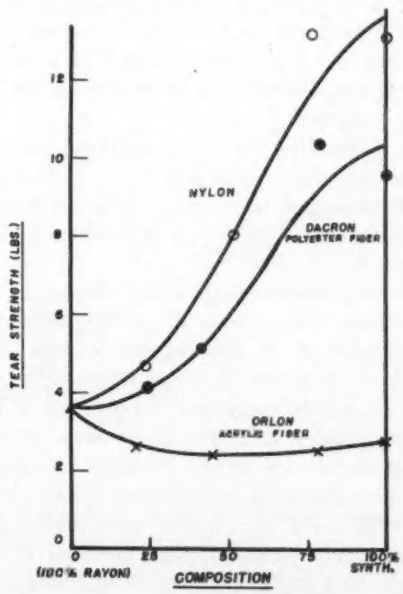


Fig. 1. *Tongue tear strength* vs. *blend composition (rayon/synthesized fibers—"tropicals").*

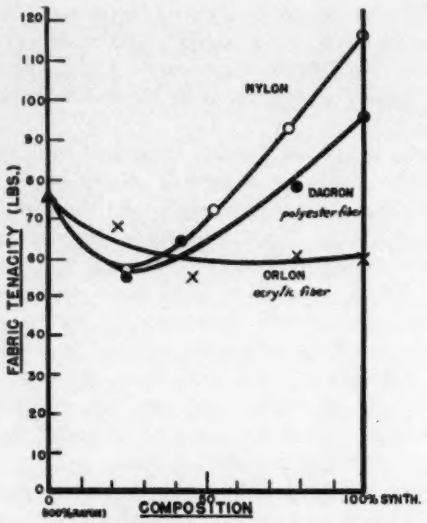


FIG. 2. *Ravel strip tenacity* vs. *composition (rayon/synthesized fibers—"tropicals").*

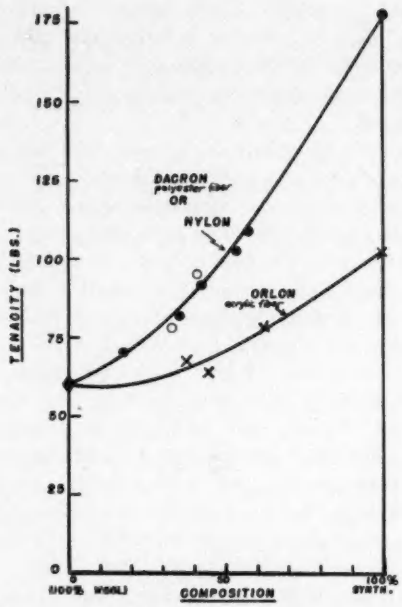


FIG. 3. *Fabric ravel strip tenacity* vs. *composition (wool/synthesized fibers—"serges").*

100% wool fabrics; and the tenacity of Orlon staple could be increased if it were desirable to do so.

When Dacron, nylon, or Orlon were blended with acetate or wool, a nearly direct reinforcement in tensile strength was found. This is illustrated in Figure 3, in which the tensile strengths of wool and blends of wool with the synthesized fibers are plotted. Additions of nylon or Dacron and, to a somewhat lesser extent, Orlon, are seen to increase the tensile strength of wool.

The explanation for lack of reinforcement by the stronger Dacron polyester or nylon fibers in some combinations can be found in the differences in stress-strain characteristics, as pointed out by Walter Hamburger [5].

Summarizing—blending either Dacron or nylon with cotton, rayon, wool, or acetate increased the tear strength of the resulting fabric over that for the appropriate control fabric of 100% cotton, rayon, wool or acetate in every case. In the cases of acetate and wool, tensile strength was increased at all concentrations but the tensile strengths of cotton or rayon were increased by Dacron or nylon only when these latter were the majority components. Additions of Orlon yielded smaller increases in tensile strengths and slight increases in tear strengths of acetate or wool.

Abrasion Resistance

A flex wet test made on a Stoll-Quartermaster Universal Abrasion Tester [10] was chosen for measuring resistance to abrasion, following, in general, ASTM–D–1175–51T. Kennedy and Weiner have shown that flex data correlate with durability [12]. Tests of this work were performed on wet samples, since the precision of data was found to be much better for all types of fibers when tested wet.

For every fabric type considered, nylon at all concentrations was found to yield outstanding increases in abrasion resistance over that for rayon, acetate, wool, or cotton; while Dacron was found to yield smaller but very marked increases. These conclusions are illustrated in Figure 4 for tropical weight fabrics of rayon and the synthesized fibers. The value for 100% rayon is at the lower left; values for fabrics containing nylon rise rapidly with added nylon along the top curve; values for fabrics containing Dacron increase less rapidly along the central curve and values for fabrics containing Orlon rise slowly along the bottom curve.

Similar changes in abrasion resistance of cotton were found for denim-type fabrics, knitted shirts, and socks. Figure 5 shows that the blends contain-

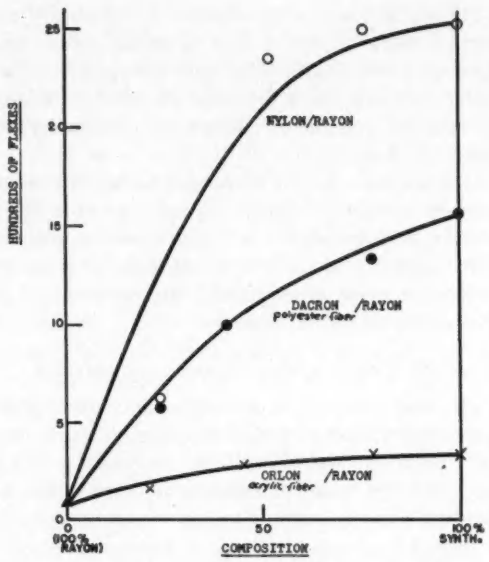


FIG. 4. *Abrasion resistance—rayon/synthesized "tropicals" (Stoll flex, wet).*

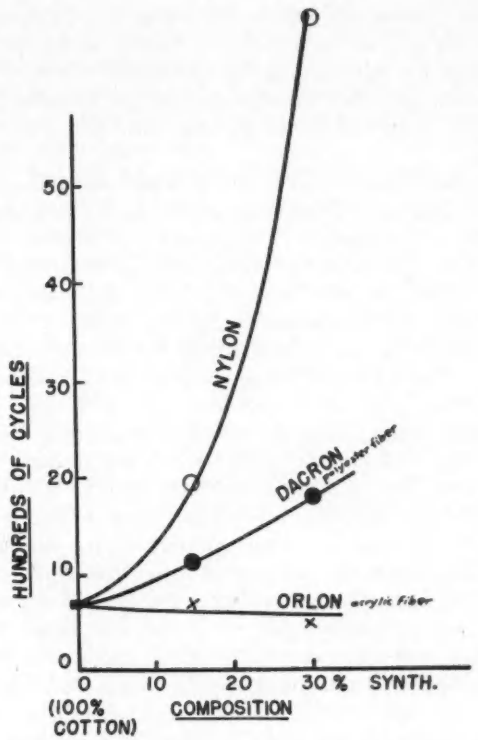


FIG. 5. *Abrasion resistance (flex, wet) cotton/synthesized denims (approx. 7 oz./yd.²).*

ing nylon have the highest resistance to abrasion, this time for blends with cotton in a denim-type construction. The behavior of nylon is similar in blends with wool in tropical-type fabrics and also in the 18-oz. Quartermaster fabric for uniforms. Actual wearing tests are in progress in order to relate these laboratory tests to actual use durability.

Crease Recovery and Stiffness at Normal Humidity

A combination of several physical measurements is required to assess the resilience and handle of a fabric. The properties of crease recovery and stiffness, which are important in this respect for suiting fabrics, were determined. The crease recovery was measured by the well-known Monsanto technique and stiffness was computed from the double cantilever or hanging heart technique. Measurements were made at 65% R.H., 70°F.

In general, crease recovery changed in approximately a straight-line manner with fiber composition. The crease recovery for a blend fell between that for control fabrics of the different fibers and in approximate proportion to the fiber concentration. This is illustrated by Figure 6, showing the data for blends and control fabrics of rayon and three synthesized fibers. The rapid increases in crease recovery with additions of Dacron to rayon are evident.

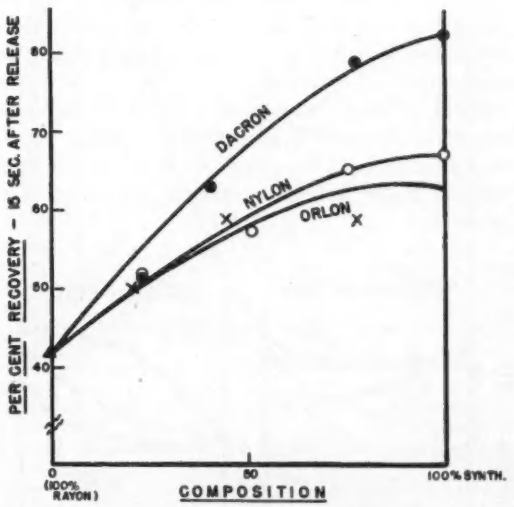


FIG. 6. *Crease recovery vs. composition (rayon/synthesized fibers—"tropicals," 65% R.H., 70°F) (Dacron polyester fiber, nylon, and Orlon acrylic fiber).*

The increases for additions of nylon and Orlon are shown by the lower curves. Similar trends were found for mixtures of the synthesized fibers with acetate and wool, although the contrast between the synthesized and the latter fibers was progressively less.

Crease recovery measurements were made on several samples of premium grade, all-wool fabrics and also on commercially acceptable, 50% rayon/50% acetate resin-treated suitings at 65% and 90% relative humidity. At 65% relative humidity the results indicated that, from a practical standpoint, 75% Dacron polyester fiber is required to raise the crease recovery of rayon to the level of premium grade wool fabrics, and 50% Dacron, to raise the rayon to the level of commercial rayon-acetate resin-treated suitings. With acetate, 50% Dacron should be sufficient to reach the level of wool. About 75% Orlon acrylic fiber or nylon was indicated to bring the crease recovery of rayon up to that of commercial resin-treated suitings.

In general, the stiffness of rayon was raised by Orlon, was unchanged by Dacron and lowered slightly by nylon; whereas that of acetate was raised by Orlon and Dacron and essentially unchanged by nylon. Wool was changed only slightly by Orlon, Dacron, and nylon. Some of the data which led to this conclusion are shown in Figure 7, where flexual rigidity is plotted against fabric composition. The extreme left of the chart shows the effect of blending Orlon, Dacron, or nylon with rayon. The central plot shows the effects of the three synthesized fibers on acetate. Finally, the chart on the right shows the small effects of nylon, Orlon and Dacron on fabric stiffness in blends with wool. These results were obtained on tropical weight fabrics. Similar results were also obtained for blends of wool and the synthesized fibers in the heavier 18-oz. serge construction.

The significance of the changes found in stiffness may be more academic than practical. Yarn and fabric geometry (yarn count and twist, pick, and end count, etc.) can affect the value of stiffness to such an extent that these variables may overshadow the effects of composition.

In summary—at 65% relative humidity, the crease recovery of blended fabrics appeared to be a linear function of fiber content and differences among the fibers appeared to be consistent and pronounced. Stiffness, on the other hand, was not changed as significantly as crease recovery.

Effects of Humidity, Dry Cleaning, Laundering

The low moisture sensitivity of the synthesized fibers suggests important contributions which they might make in blends with the hydrophilic fibers. The new fibers would be expected to improve dimensional stability and crease recovery and to assist in the maintenance of crispness of hand in high humidity and after laundering and dry cleaning.

In general, the synthesized fibers contributed significantly to the dimensional stability of blended fabrics. The extent of contribution varied with the fiber types, depending, at least in part, on the relative moisture insensitivity of the component fibers.

Effects of high humidity.—All fabrics showed lower crease recovery at 90% R.H. than at 65% R.H. Blended fabrics containing the synthesized fibers lost less crease recovery than fabrics composed of 100% rayon, acetate, or wool. Figure 8 is a partial summary of the data which led to this conclusion. It is significant to note also that at 90% R.H., a 50/50 blend of rayon and Dacron had appreciably higher crease recovery than the average of several commercial rayon-acetate resin-treated suitings, while a 50/50 Orlon/rayon was comparable in crease recovery.

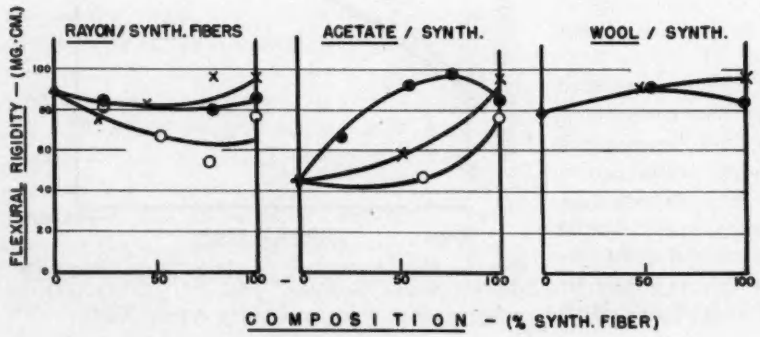


FIG. 7 *Fabric stiffness* vs. *blend composition ("6 oz. tropicals," 65% R.H., hanging heart method).* ●—● = *fabrics containing Dacron polyester fiber;* ×—× = *Orlon acrylic fiber;* ○—○ = *nylon.*

Although data of this work are not complete at humidities higher than 90%, the moist test of Bogaty [2] and data given by Fremon [4] indicate that the crease recovery of fabrics drops even faster with increasing humidity above 90% R.H. Thus the advantage for moisture insensitive fibers may be much greater than the data at 90% R.H. would indicate.

It is known that "cycling of humidity" is related to changes in dimensions of fabrics. Following the procedure, in general, of von Bergen and Clutz [11], fabric dimensional changes were measured between conditions of 15% and 90% R.H. The results for blends of rayon with Dacron, Orlon, and nylon in tropical weight fabrics are shown in Figure 9. The lower two curves show the excellent stabilizing effects of Dacron and Orlon on rayon. The uppermost curve shows nylon exerting appreciable, though considerably less stabilizing effect. Similar trends were found for combinations of wool and synthesized fibers, as reported by Dennison and Leach [3]. These effects are important, for example, in connection with the selection of the correct materials for inner-linings, the proper sewing thread for garments, and in the maintenance of the original appearance of garments.

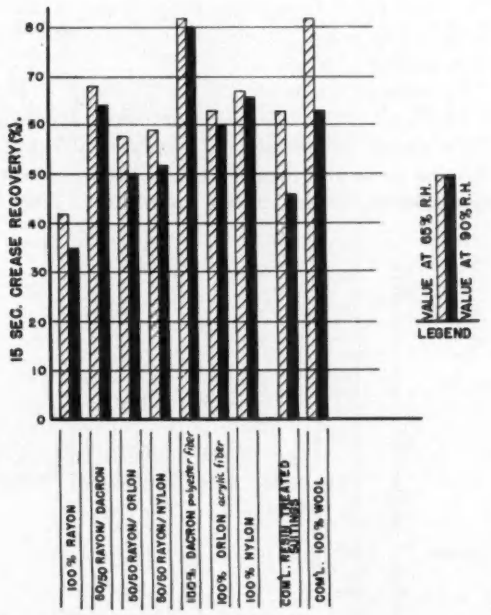


Fig. 8. *Effect of high humidity on crease recovery (commercial and rayon/synthesized fibers—"tropicals").*

Effects of dry cleaning, laundering.—Studies were made of the effect of commercial laundering and dry cleaning on crease recovery, stiffness, and shrinkage. While most suiting fabrics are often never laundered, milder "wool washes" are sometimes used for slacks and other garments.

The changes in crease recovery and stiffness, resulting from laundering or dry cleaning, were about the same for fabrics made entirely from the hydrophobic fibers and blends of hydrophobic and hydrophilic fibers. The rayon-acetate resin-treated fabrics had the greatest loss in crease recovery and stiffness, presumably due to a loss or change in the resin content. Shrinkage after ten commercial dry cleanings or launderings was found to be less for fabrics composed entirely of Dacron, nylon, or Orlon than for those of rayon, acetate, or wool. The stability inherent to the synthesized fibers was carried over into blends in approximate proportion to their con-

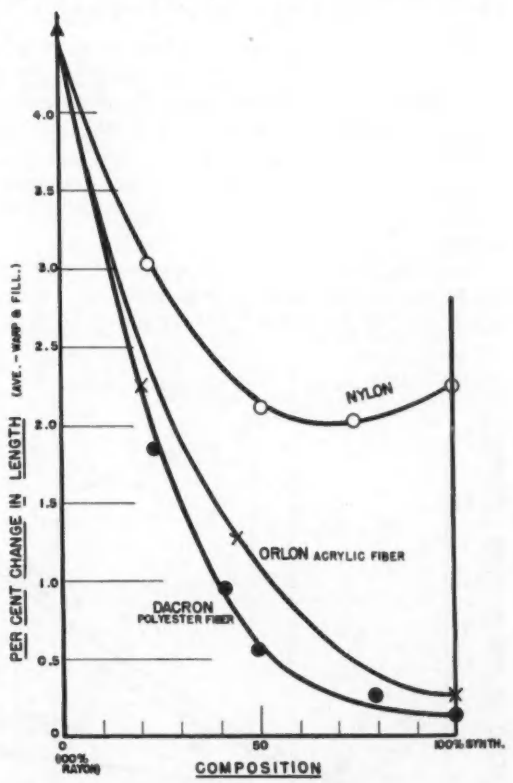


Fig. 9. *Fabric dimensional change with R.H. change (15%–90%) vs. composition (rayon/synthesized fibers —"tropicals").*

centrations. The differences in shrinkage were greater after the "wool wash" than after the dry cleaning. A portion of the laundering results are given in Table I.

In summary—the moisture-insensitive fibers produced on the moisture-sensitive fibers a definite stabilizing action to changes in humidity, to dry cleaning, and to laundering. The dimensional stability was enhanced and the crease recovery was more stable for blends of the new fibers with the older fibers than for the older fibers alone.

Wicking

The significance of the rate of wicking in fabrics has not been completely elaborated. Its importance depends on the conditions under which a garment is used. Wicking is probably disadvantageous in outer garments worn in cold, wet environments and advantageous in clothing worn in warm environments where the transport of perspiration outward is desirable.

TABLE I. SHRINKAGE OF TROPICAL-TYPE SUITING FABRICS AFTER MILD "WOOL WASH"

Fabric composition	Shrinkage (after 10 launderings) (%)
100% Rayon	10
100% Wool	6
50/50 Rayon/Dacron polyester fiber	5
50/50 Rayon/Orlon acrylic fiber	6
50/50 Wool/Dacron	1.5
100% Dacron	0.5
100% Orlon	3

The wicking tendency was measured by dipping the bottom end of a vertical strip of fabric in water and observing the height of a rise of water as a function of time. The height of rise after 30 min. was taken as an index of wicking and is shown in Figure 10. Orlon and nylon, under these conditions, showed appreciably greater wicking tendencies than wool, whereas Dacron showed only slightly higher wicking than wool. These tendencies were carried over in a nearly linear manner for blends of these synthesized fibers with wool. A practical appraisal of these differences is a subject for further textile research.

Pilling

While research on pilling has been carried out, the laboratory method for the measurement of pilling tendency is not entirely satisfactory for blended fabrics. This subject will require additional textile research.

Press Retention

The ability to retain a crease pressed in a fabric is particularly important in men's suitings, uniforms and ladies' dress goods. Thermoplastic or heat-settable, moisture-insensitive fibers, such as Dacron polyester fiber, nylon, and Orlon acrylic fiber, in contrast to moisture-sensitive fibers, impart to fabrics the ability to retain pressed creases even after thorough wetting in water.

To measure quantitatively the ability of a fabric to retain a crease, a test was developed wherein a fabric sample was pressed on a commercial Hoffman finishing press and then the crease height measured by means of a profilometer called the "Wrinkle-

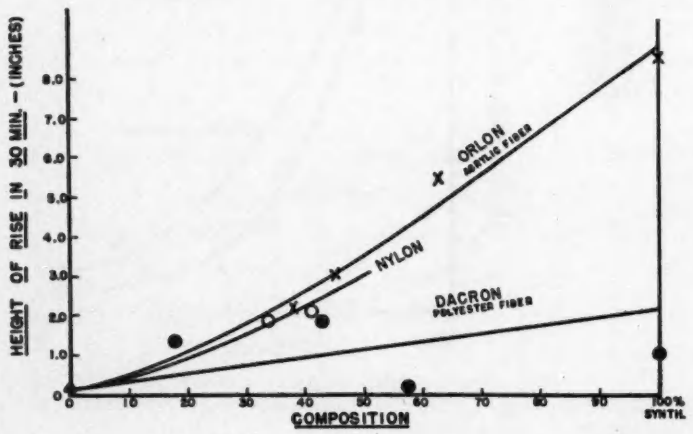


FIG. 10. *Wicking height* vs. *composition* (*wool/synthesized fibers—"serges"*).

ometer" by Hebeler and Kolb [7]. Measurements of crease height were made before and after subjecting the crease to conditions designed to test its stability. For the first condition, called "Dry" on Figure 11, the crease height was measured before and after hanging the fabric for 20 hrs. at 65% R.H. with the crease pulled open under a small constant force. For the second set of measurements, called "Wet," the crease height was determined before and after the crease had been soaked and then hung for 20 hrs. with the crease pulled open. Crease retention was taken as the percentage crease height remaining.

Results are shown in the three plots of Figure 11 for tropical weight fabrics. On the left are shown the results for blends of Dacron with wool, rayon, or acetate. It is evident from this and the similar diagram for Orlon in the center that both Dacron and Orlon exert a strong stabilizing effect on the pressed creases of blended fabrics. Nylon, as seen from the right-hand chart, apparently failed to stabilize creases under the conditions of measurements. This is explained by the fact that all fabrics, except the all-rayon fabric, were exposed to a temperature of 385°F in finishing. The temperature attained on the Hoffman finishing press usually ranges from 210 to 240°F. This range is not high enough to cause a rearrangement and fixation of the internal molecular structure for this particular fabric. Nylon is, by far, the least responsive to heat. If a "set" is imposed on nylon, its effect will not be overcome unless the severity of the original setting conditions is exceeded. Nylon will also stabilize creases if the temperature conditions are properly manipulated [8].

Local Melting

The formation of small holes by hot embers dropped on light weight fabrics has been a source of irritation to consumers for many years. This problem has received more attention since the introduction of fabrics made of fibers from synthetic polymers.

To permit a semi-quantitative comparison of the susceptibility of various fabrics to this hazard, a test has been devised in which heated pellets of known temperature are dropped on a fabric. The rate and extent of damage are subsequently observed, and observations repeated with hotter or cooler pellets until the maximum temperature at which the fabric performs satisfactorily is determined. This temperature in centigrade degrees divided by 10 is taken as the hole melting index or "Perther" rating.

Changes in Perther ratings with fiber content are shown in Figure 12. Additions of rayon to Dacron polyester fiber or nylon are seen to yield fabrics with sharply reduced hole-melting tendencies. Fabrics of Orlon acrylic fiber were satisfactory and blends of rayon with Orlon gave somewhat higher resistance to local melting. Rayon was more important in protecting Dacron and nylon blends. By additions of acetate (top-right curves) to Orlon, the Perther ratings were decreased so that about 30% acetate added to Orlon brought the resistance below the

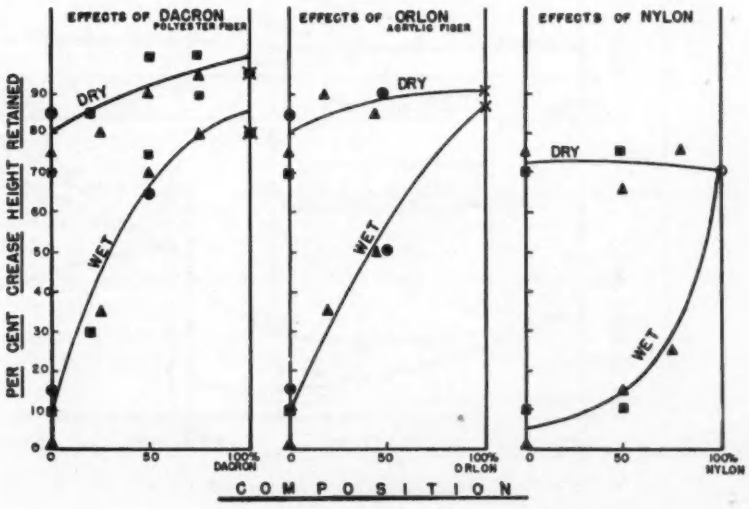


Fig. 11. *Crease retention* vs. *blend composition ("6 oz. tropicals").* ● = *fabrics containing wool;* ▲ = *rayon;* ■ = *acetate.*

satisfactory level. Acetate failed to assist Dacron or nylon significantly. As seen from the two lower sets of curves, wool is effective with Dacron.

Thus, it was found that the local melting tendencies of fabrics of Dacron or nylon were reduced sharply by adding upwards from 20% of rayon or 50% wool.

Combustibility

The rapidity with which fabrics will ignite and burn has received considerable publicity in recent months. Suiting fabrics of the constructions used in this study do not usually burn at excessive rates. However, it was considered important to determine

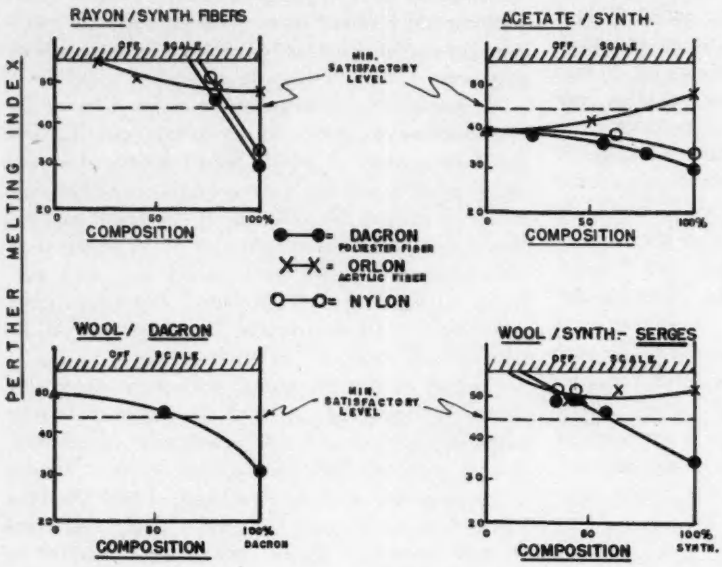


FIG. 12. *Hole melting* vs. *composition ("6 oz. tropicals") (except as noted).*

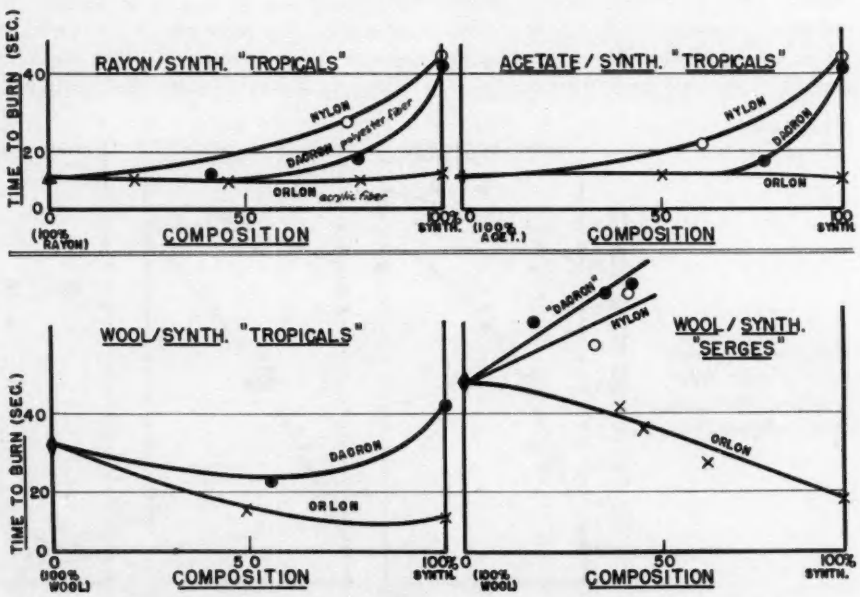


FIG. 13. *Combustibility* vs. *composition (A.A.T.C.C. Method 33–46 modified).*

how various fibers influence burning when combined in one fabric, since it has been known, for example, that combinations of nylon and "Fiberglas" will burn whereas neither fiber alone will support combustion.

A modification of the A.A.T.C.C. method 33–46 was used, wherein a sample of fabric was held at 45°, the lower edge ignited and the time to burn a given distance was determined. The time to burn was taken as an index of burning. Thus, the greater the value, the more acceptable the fabric. Results for the various blend series are shown in Figure 13.

It is pointed out that none of the fabrics showed a detrimentally low value of burning time. As seen from the two upper diagrams, the addition of rayon or acetate to Dacron or nylon resulted in a lower time to burn. Tropical weight fabrics composed of blends of wool with Dacron or Orlon burned slightly faster than the 100% wool (lower left diagram). On the other hand, additions of Dacron or nylon to wool in 18-oz. serges improved the burning index.

Static Electricity

The generation and retention of static electricity by moisture-insensitive fibers, yarns, or fabrics can be detrimental during textile processing and during end usage. During textile processing, control of static has been accomplished with good success through the application of fugitive antistatic materials or by means of external static eliminators. Permanent antistatic materials for application to finished fabrics have been sought with only partial success.

Blends of certain fibers offer an alternate means for reducing permanently the static effect either (*a*) by reducing the tendency to form static, or (*b*) by dissipating the charge through conducting fibers [1].

The severity of static generation for the fabrics of this study was measured both subjectively and objectively. The subjective determinations were obtained on garments made of the fabrics under test by requiring wearers to walk a specified distance in an atmosphere of about 34°F, 35% R.H. and then rating the severity of static according to the scale: *0* = no static, *1* = slight static, *2* = moderate static, and *3* = excessive static. The objective tests were made according to methods described by Hayek and Chromey [6].

Results of the subjective tests are shown by the curves of Figure 14. As evident from the top set of curves, rayon added to Dacron, nylon, or Orlon reduced the static appreciably. Acetate did not change the static propensity of Dacron or Orlon, according to the data of the central curve; and blends of wool with Dacron or Orlon apparently had lower static than either wool or the synthesized fibers alone. These trends were confirmed by results of objective tests, in general, except for blends containing wool. The anomaly in this latter is under study.

Application of Results

The practical application of the information developed will require much additional textile research. This work has, however, made it feasible to indicate approximate minimum percentages of fibers for the development of an acceptable degree of functionality with respect to crease recovery, press retention, dimensional stability, abrasion resistance, and tensile strength. The percentages of nylon, Dacron, or Orlon are shown in Table II.

It is recognized that the inclusion of the "indicated minimum" or even higher percentages is no

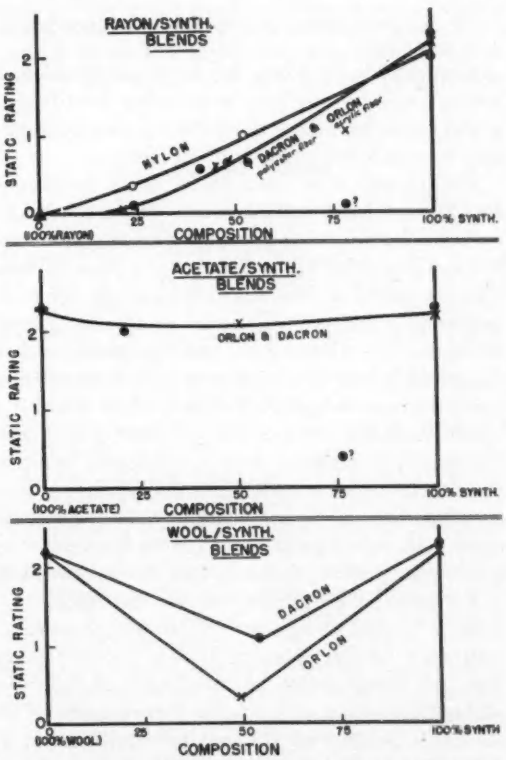


FIG. 14. *Subjective static ratings* vs. *fabric composition ("6 oz. tropicals").*

TABLE II. INDICATED MINIMUM PERCENTAGES OF CHEMICAL STAPLES IN BLENDED WOVEN FABRICS *

Fiber	Resilience (resistance to and recovery from wrinkling) (%)	Retention of press (%)	Dimensional stability to changing humidity (%)	Resistance to abrasion (%)	Tensile strength (%)
Nylon	—	data incomplete	40	15	15 acetate wool 60 rayon cotton
Orlon acrylic fiber	50 wool acetate 80 rayon	25 rayon acetate wool cotton	30 rayon wool acetate	—	adds slightly to acetate wool
Dacron polyester fiber	50 wool acetate 75 rayon	25 rayon acetate wool cotton	30 rayon acetate wool	30	20 acetate wool 60–70 rayon cotton

* Above conclusions apply for nonresin-treated fabrics.

guarantee that the particular degree of functionality desired will be attained, since other factors—*e.g.*, denier, twist, ply, fabric construction, and finishing—also may modify the properties of fabrics.

The results show that, if the fabric is designed for the indicated minimum for resistance to and recovery from wrinkling, using Orlon acrylic fiber or Dacron polyester fiber, with rayon, acetate, or wool, then the fabric will automatically possess values for retention of press, resistance to abrasion, tensile strength, and dimensional stability which will be considerably better than the values obtained when the minimum percentage of chemical fibers is used to obtain these latter properties. In other words, when the fabric is designed for the indicated minimum for resistance to wrinkling, then the over-all functionality of the fabric will be improved. If properties other than resistance to and recovery from wrinkling are more important, then a compromise may be made.

Naturally, the question arises in regard to a suitable method of applying the results of these experiments. Experience has already shown that the data are useful from the standpoint of indicating approximate areas of work for the initiation of experiments in blending, thus saving much time in the development of fabrics.

The limited subject of this paper and the summary nature of the treatment do not permit a full description of the research carried out. Thus it might be wrongly inferred from this presentation that satisfactory fabrics composed entirely of the synthetic fibers have not been made. To the contrary, fabrics made entirely of synthetic fibers are and will continue to be standard fabrics for many wearing apparel and industrial uses.

The data presented suggest that the blending of fibers possessing diverse properties is a most promising method of bringing functional and aesthetic properties together and represents a sound approach to the attaining of the desired performance in fabrics. The achievement of this objective is a challenge to research men in the textile industry.

Summary

Detailed investigations of the properties of fabric blends lead to the conclusion that fibers from synthetic and from natural polymers are complementary in nature. Thus, there are evident advantages in choosing fibers that will best suit the use to which the final fabric will be put. By studying the ultimate usage of a fabric, the textile manufacturer can choose a single fiber or a blend of fibers from synthetic and natural materials that will render the most satisfactory service and have the desired aesthetic properties.

In this investigation, nylon staple, Dacron polyester staple, or Orlon acrylic staple was combined with rayon staple, acetate staple, or wool. Two component blends were made containing one of the new

TABLE III. Summary of Fiber Contributions in Blends

	Contributions of synth. to older fibers									Contributions of older fibers to synth.								
	Dacron to:			Orlon to:			Nylon to:			Wool to:			Rayon to:			Acetate to:		
Fabric property	*W*	*R*	*A*	*W*	*R*	*A*	*W*	*R*	*A*	*D*	*O*	*N*	*D*	*O*	*N*	*D*	*O*	*N*
Strength	++	*	++	+	−	+	++	*	++				*	+	*			
Abrasion resist.	++	++	++	−	+	+	++	++	++									
Crease recovery (dry)	−	++	+		+	+		+	−	−	+	+						
C.R. at high R.H.	+	++	++	−	+	+	−	+	+									
Stability to R.H. change	++	++	++	++	++	++	−	+	+									
Stability in dry cleaning & laund.	+	++	+	+	+	+	+	+	+									
Wicking	(*O*, *N*, and *D* increased wicking of *W* but added research needed to determine significance)																	
Pilling resist.	(Added research needed to establish significance of laboratory pilling data for blends)									+	+	+	−	+	+	−	+	
Resistance to hole melting			−	−	−	−			−	+	−	+	++	−	++	−	−	−
Rate of burning	+	+	−		−	−	+	+	+		+			−		−	−	
Press retention	++	++	++	++	++	++		+	+									
Static resistance			−			−			−	+	+	+	+	+	+	−	−	−

\+ = Significant contribution
++ = Major contribution
− = Minor change

W–Wool
R–Rayon
A–Acetate

D–Dacron polyester fiber
O–Orlon acrylic fiber
N–Nylon

* Tear strength of *R* given ++ by *D* and *N* but tensile given + only when *R* is minority component.

and one of the old fibers. The resulting blends of fibers were carefully processed into yarns and fabrics. Yarn diameter and twist along with fabric pick and end count and finishing were controlled to give as comparable fabric structure as practicable throughout a given set of fabrics.

Among the fabric characteristics examined were strength, abrasion resistance, recovery from wrinkling, ability to retain a pressed crease, flammability, and the sensitivity of certain of these properties to humidity, dry cleaning, and laundering. Results are briefly summarized in Table III.

Generally, Dacron polyester fiber in combination with wool, acetate, or rayon increased fabric strength, abrasion resistance, press retention, wrinkle recovery, and stability to changes in relative humidity when compared with 100% wool, acetate, or rayon fabrics. Orlon acrylic fiber increased fabric strength when blended with wool and acetate. Blends of Orlon with rayon, wool, or acetate showed increases over fabric of the appropriate older fiber in stability to dry cleaning, laundering and humidity changes, and in ability to retain pressed creases. Abrasion resistance and crease recovery at normal and high humidities were increased by Orlon when blended with rayon or acetate. Nylon contributed substantially to increased abrasion resistance in blends with wool, rayon, cotton, or acetate. Stability to changes in relative humidity was improved by nylon added to rayon and acetate.

The results of this work have been useful in fabric research by indicating approximate blend compositions for the design and development of improved fabrics.

Literature Cited

1. Ballou, J. W., Textile Research Journal **24**, 146–55 (1954).
2. Bogaty, H., Hollies, N., Hintermaier, J. C., and Harris M., Textile Research Journal **23**, 536–44 (1953).
3. Dennison, R. W., and Leach, L. L., *J. Textile Inst.* **43**, P473–94 (1952).
4. Fremon, G. H., "Fibers from Synthetic Polymers," London, Elsevier Publishing Co., 1953, p. 466.
5. Hamburger, W. J., *J. Textile Inst.* **7**, P700–718 (1949).
6. Hayek, M., and Chromey, C. F., *Am. Dyestuff Reptr.* **40**, 164, 225 (1951).
7. Hebeler, H. H., and Kolb, H. J., Textile Research Journal **20**, 650 (1950).
8. Heckert, W. W., "Technology of Synthetic Fibers," New York, Fairchild Publications, 1953, p. 132.
9. Quig, J. B., and Dennison, R. W., *Ind. Eng. Chem.* **44**, 2176–83 (1952).
10. Stoll, R. G., An Improved Abrasion Tester and Its Applications for the Evaluation of the Wear Resistance of Textiles, Textile Series No. 54, OQMG (1949).
11. von Bergen, W., and Clutz, C. S., Textile Research Journal **20**, 580 (1950).
12. Weiner, L. I., and Kennedy, S. J., *J. Textile Inst.* **44**, 433–474 (1953).

Problems in Fiber Blends*

J. B. Goldberg†

THE ATTRIBUTES of fiber blends are many, and there seems to be no doubt that they will continue to grow in popularity, greatly stimulated by the introduction of the newer synthetics. Little has been said, however, of some of the problems confronting the mills handling such blends. We are all fully aware of the tantalizing technological and psychological difficulties facing the producers of the man-made fibers during these days of scientific marvels. But it is the responsibility of the mills to carry out efficient and trouble-free processing of two or more fibers into yarns for the fabulous fabrics which the consumer has been taught to demand. Whether they be the children of desperation rather than inspiration and grow up into fabrics of futility rather than utility is of secondary importance at this time.

Perhaps the day will come when, like that popular creation now offered to the modern or lackadaisical housewife, the prepared cake-mix, blended fibers will ultimately be made available to turn out a foolproof product with a choice of several flavors. Right now the mills must make their own concoctions, blending the bitter with the sweet, the strong with the weak, the plentiful with the scarce, and the costly with the cheap. At times it seems that they are trying to turn out an angel food cake from a devil's food mix. It is conceivable that some day a single fiber will possess all of the properties necessary to yield a fabric to meet specific requirements of tactile and visual appeal coupled with outstanding performance. You have heard of the exploratory work being carried out at the Textile Research Institute in the combining of two fiber-forming compounds in such a manner that they may result in the production of yarns with tailor-made properties. When any one fiber, whether by machination or imagination, is created to fulfill every need, that will be the day it will have truly earned the right to be called a "miracle" fiber. Until then, however, it appears that the mills will have to be burdened with the responsibility of trying to make a homogeneous yarn from a conglomeration of variables. If a competent chef were confronted with the multitude of weird combinations in his kitchen that the mill man sees before him, he would probably burst into tears, resign, and go back to his mother's plain cooking.

Mindful of the preceding speaker's presentation on the "Complementary Functions of Fibers in Fabrics," perhaps an appropriate title for this dissertation would be, "The Uncomplimentary Characteristics of Fiber Blends." But all of these introductory remarks are not intended to convey the impression that the task is an impossible one, and it is my sincere belief that blends in some form or other are an indispensable part of the fabrics of today and tomorrow.

Contamination—Fly

Starting with a simple and popular type of blend, viscose and acetate, regardless of the proportions of each, the mill man is immediately alerted to a host of problems which were unheard of in earlier days. When a yarn spinner, just about reconciled to using rayon, after having been successful in running only cotton, even if his success did entail a bit of speculation on cotton futures, finally decides that he must handle acetate-viscose blends, the first reaction is one of horror. Unlike the man who saw his mother-in-law drive over the edge of a cliff in his new automobile, he is not faced with mixed emotions. Even when whispered softly, the single word "contamination" is enough to bring on consternation. "Fly" is a bogy that frightens every mill man. Cotton fly among brother cotton fibers may pass unobserved, but acetate fibers deposited among their cousins, viscose fibers, do not go unnoticed after the goods are dyed. Moreover, and especially terrifying to contemplate, such contaminating fibers are not visible in the greige yarn or fabric. Vice versa, of course, lest it be construed that acetate is a monster, stray viscose fibers lurking out of place among acetate fibers or yarns are likewise undesirable aliens.

Uneven Blending

Perhaps one of the major single causes of tremendous dollar losses to every mill that has run blends of acetate and viscose is the tragedy of uneven blending, or variations in the stipulated proportions of the two

* Presented at the 1953 Annual Meeting of Textile Research Institute in New York City, Nov. 13, 1953.

† Chemical Engineer, Consultant to the Textile and Allied Industries.

fibers. Here again, like double exposures on film, the results do not become apparent until later development—in this case the dyeing of the fabric. The accurate weighing and intimate mixing are certainly processing problems not impossible to control, but there is always the possibility of variations in moisture content which can make the most accurate weighings meaningless. The mill must take every precaution to be certain that the moisture regain of each bale is known, or at least that the lots of both types of fibers going into the blend are at moisture equilibrium before starting. The moisture regains of viscose and acetate are markedly different, and what appears to be only a slight difference in the conditions under which the bales are received or stored can result in major variations in the net weight of the conditioned fiber. In yarns or fabrics which are intended to be cross-dyed the results can be disastrous. Mention was made of the comparatively simple problem of controlling weighings. In actual practice, however, if a mill does what is commonly known as "sandwich" blending and weighing is by hand, the human element is always present as a serious source of trouble.

Nonfugitive Tints

The tinting of fiber for identification purposes is common practice and quite necessary in most cases. Fortunately the variety of dyestuffs available for viscose-acetate blends is reasonably large. Consequently there is no great difficulty in selecting distinctive colors which are completely fugitive without danger of staining the untinted fiber in the subsequent boil-off and dyeing operations. There have been instances on record where the particular finish used on one of the component fibers has resulted in the retention of the normally fugitive tint applied to it, or transfer from the other fiber, but such cases are comparatively rare. It is customary practice to test such tints before they are put into use. What is frequently overlooked is the fact that the steaming of yarns, as, for example, in twist-setting operations, prolonged contact with certain desizing agents, or the use of some synthetic detergents in normal boil-off procedure are all conditions under which there may be a setting of a tint or lessening of its fugitiveness. Obviously it cannot be assumed that a tint is completely fugitive because it was laboratory tested by direct immersion in a soap-scouring bath.

Another source of difficulty is the presence of impurities in the tint, or the accumulation of dirt or contaminating materials in an otherwise readily removable tint solution. Lack of lightfastness may present still another annoyance if it is discovered too late that what started out as a bright identifying color in one process in the mill ended up as an anaemic, confusing shade by the time the yarn was ready for the loom. While it is true that a wide range of completely satisfactory dyestuffs may be available, most mills today are troubled by the fact that they are obliged to run scores of blends. As a result, every obtainable tint must be utilized and they are forced to use some colors or combinations of colors which are not as fugitive as others. To this day, many dyers do not seem to realize that just because Mill *A* uses an easily removable blue tint for a specific blend of fibers, it is not practical for Mill *B* to use the same tint on a similar blend for the simple reason that it may already be using that particular color for some other fiber combination. In many instances it is necessary to increase the depth of shade of a tint to provide ready visibility of this only distinguishing mark in the mill, and what might be easily removable in low concentrations is not so readily eliminated in normal scouring when present in the higher concentration. With the trend toward more rapid processing in the dyehouse, too, and appreciating the fact that certain forms of boil-off do not provide for prolonged scouring and violent agitation, the mill man has added woes in the selection and application of tints. At one time some of the staple fiber producers supplied pretinted stock, but the assortments of deniers and staple lengths as well as the complexity of blends run by the various mills soon made this endeavor impractical.

For illustration purposes, the perplexing factors of contamination, uneven fiber distribution and tint removal have been discussed as applied to viscose and acetate, since until the newer synthetics appeared on the scene, those two materials accounted for a large percentage of the mixtures in popular use. But fly, uneven blends and unremoved tint are problems which plague the processor of all fiber mixtures. In fact, the introduction of nylon, the acrylics, Vicara, and Dacron polyester fibers has created a more serious situation, since in dealing with costlier staples, the losses due to errors in manufacture or judgment are substantially greater. Higher charges for dyeing and finishing of most of the fabrics containing the newer synthetics also account for a snowballing of losses when such latent defects are encountered.

Fiber Breakage, Lubrication, Surface Effects

The comparatively low strength of acetate staple makes it particularly vulnerable to fiber breakage during processing, and the resultant grouping of small bunches of fiber or neps of single broken fibers has a most detrimental effect on the appearance of cross-dyed goods. It must be remembered, too, that the differences in specific gravity as well as surface friction properties are factors which may affect intimate mixing. Usually the degree of opening of acetate and viscose, or even of similar fibers from different producers, varies appreciably, so that extreme precautions must be taken to assure uniformity of subsequent blending.

Blends of wool with viscose present a somewhat similar situation with regard to the use of tints, fiber breakage and contamination, especially if the fabrics are to be cross-dyed. In hopper feed blending, there is the danger of selective feeding of fibers which differ in specific gravity or degree of opening. Since the regain of wool and viscose are more nearly alike, slight differences in initial moisture content are not likely to be quite so serious as in the case of viscose-acetate blends. If the viscose staple lacks crimp, the use of an oil lubricant is generally suggested. When the application is not executed properly and oil distribution is uneven, there is certain to be difficulty due to fiber matting and breakage where there are localized heavily oiled areas. Incomplete drying of viscose blends which have been wet out in applying tint solutions or emulsions may also lead to excessive fiber breakage and neppiness, since the viscose loses so much of its strength while wet.

To obtain certain effects in the finished fabric, it is often desirable to utilize a large percentage of dull viscose staple in a blend. The surface characteristics of pigmented viscose are likely to be enough different from those of bright fiber so that there is greater interfiber cohesion necessitating a slower carding rate on the woolen system. Density differences between wool and rayon can also result in fiber separation in certain blending operations where air-conveying systems are employed to effect an intermingling of the fibers in bins.

Blends of viscose and cotton have not yet achieved a great deal of popularity in the United States. It is evident that choice of denier and staple length of the rayon, as well as selection of the cotton, percentage of each and decision of whether to use combed or carded fibers, can materially affect the appearance and characteristics of the resultant yarns. Acetate and wool combinations have attracted some interest in recent months, but in most respects the problems in the mill do not appear to be any greater or more serious than the processing of viscose and acetate.

Newer Synthetics—Static

The advent of the newer synthetics, particularly those of the hydrophobic type, has undoubtedly added to the worries of the mill man. As suggested when I addressed an American Chemical Society meeting almost two years ago, the producers of these newer test-tube triumphs were not thinking of the men in the mill when they prophesied "easier living" through use of their latest creations in apparel and household fabrics. Despite their shortcomings—and what product of nature or man is born without inherent deficiencies—the synthetics are here to stay because they can make real contributions in our constant search for better fabrics. Nevertheless, we must admit that they have brought more headaches to the maker of blended yarns.

Perhaps the outstanding characteristics in the minds of most people who have processed the hydrophobic fibers is their tendency to generate static electricity. Whereas the cellulosic fibers, readily responsive to the neutralizing effects of higher humidity conditions, have posed no great problems in this respect, the nylons, acrylics, and Dacron polyester have been much more annoying. The use of various devices to reduce or eliminate the charges generated have been most helpful, and the fruits of the chemists' resourcefulness to overcome this handicap in the form of antistatic finishes applied at some stage of fiber manufacturing or, even in the mill, have fortunately minimized the seriousness of this undesirable property. Not too long ago, when it appeared that the fiber producers were not successful in the selection of antistatic finishes for their newer products, it was not unusual for the mills to try to alleviate the balky behavior of such chemical fibers by applying antistatic finishes themselves. Unfortunately, it was later learned that in some cases such "home remedies," while appearing to correct the static condition, resulted in scouring or dyeing faults due to incompatibility with the finish previously applied by the yarn producer.

Considerable study has been made of the relative degree of static generation of each fiber and during each mill process, and to the classification as to which

developed positive and which developed negative charges. At times it has been proposed that the judicious blending of the proper amounts of a negatively charged fiber with one which generated positive charges might result in a self-neutralizing combination, but this suggestion has not been too diligently pursued. Obviously, the mixing of two or more fibers is usually designed with more consideration given for its economy, appearance, hand, or utility in a fabric rather than for its ease of handling in the mill. Since it is fortuitous that blends of the hydrophobic fibers with viscose or wool are both desirable and popular, the presence of reasonable amounts of those higher moisture-retaining fibers aids in reducing the static electricity annoyances encountered when running yarns composed of 100% acrylic, nylon, or Dacron staple. Thus, for example, one fabric has been marketed with 90% Orlon acrylic fiber and 10% rayon added to reduce the static charges to a degree where processing is not troublesome. Similarly, the hydrophilic properties of Vicara zein fiber have been useful in dissipating the static encountered with the other newer man-made fibers. Lack of compatibility of the antistatic agents used on the synthetics with certain lubricants used on wool is not to be overlooked and the wrong combination can bring dire consequences.

Effects of Deniers, Lengths, Stress-Strain Properties

One fiber property which contributes to blending difficulties is that of stiffness. Realizing the advantages of using a coarse denier viscose to impart greater firmness or stiffness to a yarn and fabric, it also becomes apparent that at the same time it is desirable to have greater fiber length for most efficient conversion into yarn. Handling longer fibers necessitates machinery changes which may or may not be justified by the advantages to be gained in hand of the finished fabrics. To obtain optimum yarn strength, too, more fibers per unit cross section are needed, which in turn means that finer deniers are dictated. If the fiber tenacity is relatively high, fiber breakage is not likely to be of great concern. At times it is necessary to select fiber lengths or deniers which are not the best for the end product. The development of higher tenacity viscose staple in finer deniers is welcomed by designers and mill men alike in their search for means of creating the types of blends they would like to produce with no sacrifice of yarn quality or efficiency of operations.

The processing of fiber blends with large differences in individual fiber diameters makes for general yarn evenness, and the usual mill man's complaint is that he can spin even blends when the stylist calls for uneven linen-like yarns, and uneven yarns when he is besieged with demands for a smoother, more even spun product. The introduction of variable length fiber was offered as an imitation of the natural length variations in a representative wool top, but there are still a number of technicians who feel that just because nature provides us with a nonuniform product of necessity is no reason why man should try to imitate a natural fiber's deficiency.

Recognition of the important effect of fiber stress-strain characteristics is imperative for intelligent utilization of the newer synthetics. When those characteristics are similar, there is an increase in yarn strength, but where they differ appreciably, the net result is bound to be a reduction in yarn strength, excessive ends down, and general manufacturing difficulties. When small amounts of nylon are blended with cotton for the purpose of increasing abrasion resistance in the resultant yarn and fabric, there is a definite loss in yarn strength. On the other hand, similar amounts of nylon blended with wool add to the yarn tenacity and improve its processability. Unfortunately, the mill must produce yarn blends which satisfy fabric end-use characteristics, and little sympathy is extended for the multiplicity of inconveniences introduced by efforts to run mixtures of fibers which do not get along too well together.

As mentioned earlier, the surface characteristics and frictional properties of fibers play an important part in their behavior in blends, and it is not unusual for fiber movement to result in some unwanted or unlooked-for results in the final yarn. In a blend of fine denier nylon and coarse wool, fiber migration tends to cause the nylon to spin to the core of the yarn, with the result that any anticipated improvement in surface abrasion resistance does not materialize. It has been found, too, that in blends of Dynel with wool there is likewise a tendency for the former to move toward the center of the yarn, which may or may not be desirable, depending upon what the blender is trying to achieve.

The literature is full of references to the optimum opening, carding, drawing, and spinning conditions for the newer synthetics in 100% form. However, it is apparent that in combining two or more fibers to produce a particular kind of yarn, one must of necessity effect a compromise. The type of opener, card,

beater speeds, card clothing, operating speeds, settings, coarseness of pinning, tensions, size of lap and sliver, twist multiples, and roll settings are but a few of the variables which must be considered for each type of fiber, its length and its denier. Yet the mill man is obliged to decide upon a single optimum combination of conditions for a specified yarn construction. To avoid split laps, card loading, web breakage, lapping, and excessive neps, he is usually compelled to reduce his rate of production to below what might be practical in running a single fiber. The end result is certainly a compromise.

In the processing of nylon staple, its slow recovery from stretching requires the avoidance of excessive tension to avoid subsequent cockling in the spun yarn. Contamination of nylon with dirt or grease is especially undesirable because of the great difficulty in soil removal from the greige goods. When oils are applied to other components of blends with nylon, there is considerable danger of such oils causing the nylon to mat and form pills in later operations.

Dacron staple possesses frictional characteristics which necessitate higher drafting forces than are customarily required with wool, so that the handling of a blend of those two fibers again calls for a "middle of the road" approach. At the same time, permanent stretching is conducive to lack of control in subsequent processing. If Dacron tow is used and is converted to staple on the Pacific converter, there is a possibility of fiber adhesion, and the resultant "married" fibers can be responsible for quite an unhappy family life when they make themselves at home with other fibers used in a blend. Oddly enough, too, the trend established by a single successful blend of fibers often forces a mill to run exactly the same mixture, even though the processing facilities or experience of that particular mill would normally lead it to select a slightly different combination for maximum efficiency and optimum yarn quality.

Spun-dyed or dope-dyed man-made fibers and yarns have become more popular in the United States during the past few years. While an appreciable quantity of dyed rayon staple is spun into yarns in single solid colors, a certain amount is also being consumed in combination with white viscose as well as with other kinds of fibers to yield novelty effects. Contamination by stray fibers or "fly" of any kind has already been mentioned as a hazard which causes endless trouble to most mills using more than one fiber, whether they be of natural or synthetic origin. With the new interest in dyed fibers, currently limited principally to viscose, the danger of fly is considered particularly serious, although it must be realized that single colored fibers are not likely to be readily seen unless they are very dark in shade and the fabric is finished white or in light shades. Consequently, it has been proposed by some technicians that the use of dope-dyed fiber in tow form for conversion to spun yarns would simplify matters. Unfortunately, however, if this technique is employed, apart from depending upon a more costly raw material, since tow is priced higher than staple, the problem arises of how to create blends. Perhaps another real "miracle" yarn will be a multicolored tow. At the moment this seems impossible to visualize, but perhaps the ingenious engineer or crafty chemist will find a way to inject various colors into the solution as each filament emerges from its respective hole in the spinneret.

The warp sizing or slashing of blended yarns is again an area in which a compromise is necessary, since slashing ingredients and techniques which are best for 100% rayon, acetate, or the natural fibers are not suited for the newer hydrophobic creations of man. When the percentage of the hydrophobic fibers in a single spun yarn is high, it is customary to apply sizes such as are usually employed for those fibers, but the efficiency of such slashing is certain to be reduced by the presence of those fibers which do not accept the older types of sizing materials. Before the introduction of Type 42 Orlon, slashing temperatures which were ordinarily satisfactory for viscose were found to be excessive for Orlon blends and resulted in differential dyeing and streakiness due to uneven drying temperatures.

In conclusion, this has been a review of some, but not all, of the problems of blends at the mill. Textile spinners and weavers are justified in resenting the suggestion that technical skill and research are exhibited only by chemical manufacturers or fiber producers. In spite of the many obstacles which arise daily in their paths, mill men have certainly exhibited no small amount of fortitude and aptitude in coping with those problems, turning out hundreds of attractive and functional blends to meet every consumer need. If miracle makers are the order of this day and age, and halos are in vogue, let the fiber producers move over on their pedestals and make room for the mill operators without whose skill and ingenuity there would be no blends.

Some Problems of Blending*

Milton Harris†

OVER THE YEARS, it has been my privilege to appear before these meetings several times—and it is always an enjoyable experience. But the assignment which was given me several months ago for today's discussion, which at that time seemed a relatively simple one, has now become one of the most formidable I have ever tackled.

I thought it would be simple because the subject of blending is probably one of the most widely discussed in the textile industry of today. There have been numerous discussions and symposia and one finds many published articles dealing with this subject. It has been popular to discuss the virtues of blending and, for example, to compare the trend in blending of fibers with such scientific achievements as the development of the alloys in the metallurgical industry. This is a reasonable comparison from some points of view; it is quite inadequate from many others. Actually, it is amusing to note that there are two definitions for the term alloy. One, the most widely used, denotes the beneficial effects of fusing two metals together. A less widely known one is that an alloy or blend is "An admixture of anything that lessens the value or detracts from the quality." I am sure that there are some here who feel that the latter definition is a more appropriate one for some of the blends on the market today.

In this discussion I am not going to emphasize the virtues of blending but rather feel that more can be gained by considering some of the problems and difficulties. At the outset, however, I want to make it clear that I am not taking a negative point of view of the subject. Rather, I feel much more progress will be made if we recognize these difficulties and the pitfalls that may be encountered. Personally, I am convinced of the great advantages that can accrue from intelligent blending.

At this point let us ask ourselves why we want to blend or what we might accomplish through blending of fibers. One of the most obvious reasons for blending involves price considerations and most of the early blending was done for such purposes. At first glance, this would appear to be a problem in simple arithmetic. Actually, it may be rather complex, especially if one considers such things as performance to price ratios. The importance of blending for economic reasons must not be minimized, especially when one considers the mass markets in the world where the standard of living is constantly being raised, and which continue to demand better low priced clothing and household fabrics. There is little that we can add here except perhaps to note that in a buyers market as we have today, there will be a continuing demand for maximum performance at a minimum price.

Another newer and less widely recognized reason for blending is to aid in production efficiency. There are a number of mills that are adding around 5% of nylon staple to improve spinning and weaving efficiencies, and are not even mentioning the presence of this much publicized fiber. I point this out, since as many here know, much capital has been made by gimmick promotions of adding small amounts of certain well-known fibers, in amounts or under conditions where they cannot possibly do any good.

Today, however, much of the attention in blending is directed toward improving functionality, such as comfort, ease of maintenance, shape holding, and durability, or aesthetic properties, such as hand, color, etc. The achievements in some of these areas are easily demonstrated—in others, only with great difficulty. A major difficulty lies in the fact that all too frequently, improvements in one property are accomplished at the expense of others. You are all familiar with the contributions of certain hydrophobic fibers to shapeholding at high humidities; and to the simultaneous disadvantages caused in dyeing and by static generation.

Another way of looking at the blending problem is that all fibers have desirable as well as undesirable properties and through blending it is possible to make use of the desirable component properties. This is the alloy concept of blending. It is interesting to note that in doing this, there has been a marked tendency to produce fabrics not too different from more or less standard fabrics. This is undoubtedly controlled in

* Presented at the Annual Meeting of Textile Research Institute in New York City, November 13, 1953.

† Harris Research Laboratories, Washington, D. C.

part by consumer resistance to the rapid introduction of radically new developments, which other industries such as the automobile industry, have learned is not easily accomplished. In addition, of course, there is the practical advantage of using all types of existing equipment and processing know-how.

There are a number of factors which make the discussion of problems of blends a frightening one. The first concerns the great complexity of the subject. The problem of blending is more than a problem in fiber and fabric technology—it is also a problem in organic chemistry, physical chemistry, physics, engineering biochemistry, physiology, and psychology. We talk of "engineered fabrics," but unfortunately much of the progress along these lines is still being made through empirical methods. The theoretical aspects have only been tackled in recent years beginning with the classical work of Peirce, and more recently carried on in this country by Prof. Schwarz, Dr. Hamburger and associates, Hoffman and associates, Fourt, the T.R.I. group, and a few others. If we just examine a partial list of the factors which affect fabric engineering, as listed recently by Dr. Hamburger, we can better appreciate the complexity of the subject.

(*A*) *Fabric properties.*—Determined by; (*1*) design, (*2*) compactness of weave, (*3*) tension during weaving, (*4*) finishing treatments, and (*5*) yarn properties.

(*B*) *Yarn properties.*—Determined by; (*1*) fineness, (*2*) twist, (*3*) cross-section diameter, and compactness, (*4*) surface character, (*5*) finishing treatment, and (*6*) fiber properties.

(*C*) *Fiber properties.*—Determined by; (*1*) orientation of molecules, (*2*) cross-section area, and shape, (*3*) length, (*4*) crimp, (*5*) surface, and (*6*) chemical nature of the molecules.

Offhand, this many variables would appear to constitute a mathematician's nightmare, and if we superimpose blending on top of this, all I can do is to express my great admiration for a courageous lot of people who are tackling this problem. Actually, however, real progress is being made and in general, the problem is being attacked from two points of view: (*1*) from fiber to yarn to fabric; (*2*) the reverse.

Another factor, which makes the problem somewhat difficult to discuss, results from the fact that much of the blending today is concerned with the use of synthetic fibers, and large segments of our industry have become unusually sensitive and even touchy about the subject. If one discusses the strength or toughness or hydrophobic properties of certain new fibers in relation to quick-drying fabrics, one is considered pro-synthetic. If one speaks of hydrophobic properties in relation to dyeing troubles or static properties, one is labeled anti-synthetics or pro-natural fibers. If one should dare ask why Boolon (which is fiber *X* spelled backwards) is not doing well—it would probably label one as being ultra-conservative, old-fashioned, and against everything.

It might be pertinent to inquire as to the cause of this sensitivity and touchiness. I am sure that the answer is not a simple one, but an important contributing factor has been the "overselling" or "miracle fiber" phases of synthetic fiber history. In view of the complexities and difficulties of evaluation, it was natural that mistakes would be made, and will continue to be made; and these have tended to build up certain manufacturer and even consumer resistance. Although this is costly and painful for the producers of synthetic fibers, it should in the long run lead to a greatly improved synthetic fiber industry and to a sounder textile industry.

Most technical and research people deplore the "miracle" fiber approach, but I am afraid it was in part a natural consequence of some of our own utterances and enthusiasm. Research people just as frequently oversell research and its potentialities as sales people oversell merchandise. Organic and polymer chemists have for years talked of tailor-making the ideal fiber and other high-polymer systems (rubber, resins, and plastics) and indeed have made tremendous strides along these lines. But unfortunately, "miracles" involve another few orders of magnitude.

Great enthusiasm for synthetic chemical fibers was picked up when the chemical industry took a long look at the textile industry and saw something startling. As so ably expressed by Carl Setterstrom, they saw in 1951, a textile industry consuming raw fibers in excess of $4 billion, a sum equal to the combined sales of all aliphatic and aromatic chemicals, all plastics (excluding fibers) and all lubricants and motor fuel additives. The tremendous potential in the form of new chemical fibers was obvious, especially in view of a rapidly increasing population and a widespread increase in standard of living. There are many who feel that this represents the greatest frontier for expansion of the chemical industry, and indeed, it may be that just as the demand for synthetic dyes helped spark the growth of the synthetic organic chemical

industry during the first half of this century, the synthetic fiber industry may make a similar contribution during the latter half. I am sure that this reasoning is sound, but I am afraid that there are many who did not realize that the problem of making the chemical polymer was probably the simplest phase of the job; that the real problems were concerned with the difficulties of evaluations in terms of given end-uses, and in changing manufacturers and consumers habits. These require much time.

Still another factor and one which I should like to consider at greater length in this discussion is that the differences among many similar but blended fabrics as used in our everyday life are real, but often subtle, and although they may be perceived, their absolute value is not always readily determinable. Consider for a moment the problem of regulation of body comfort. For extremes of temperature, these considerations do not apply. Under very hot conditions in the absence of direct radiation, ideally, no clothes at all would constitute the most comfortable situation. At the other extreme, for sub-zero conditions, as encountered in the far north, one requires a sort of Buck Rogers uniform. But for the masses, who live in more or less temperature controlled houses and offices, who drive autos, etc., the effects and advantages of blending require careful demonstration.

I am sure that by this time, you may be convinced that the problems of blending are very complex indeed and that there are no simple rules or formulas for telling you how to mix fibers *a*, *b*, and *c* to get the ideal fabric. There is a considerable literature which anyone interested will find helpful for special situations. In this connection, it should be emphasized that most of the blending problems become highly individualized and must be viewed from special vantage points. A good example is found in the differences between civilian and military approaches to the problem. In the military, functionality has the highest priority; in civilian goods, style or price occasionally outweigh functionality. This should not be interpreted to mean that functionality is not important for the latter; in fact, increasing emphasis is being put on this point.

It may be worthwhile to make a few generalizations which can be of help to those who are working in this field. In assessing the contributions of various fibers, it is relatively easy to demonstrate the positive advantages of some blends. Excellent examples are: The wool or cashmere blends with staple nylon in socks, whereby the wear-life may be increased manyfold. The advantages of Dacron and certain other hydrophobic fibers from the point of view of crease resistance under conditions of high humidity, or the contribution of Vicara to hand, are readily shown. The chemical stability of the acrylics, the additional flame resistance of Dynel, and many other positive and desirable properties can be cited.

When it comes to questions of warmth or comfort or some aesthetic properties of blends, the evaluations become very much more difficult. It has frequently been shown that in laboratory testing devices, thickness equals warmth. However, under actual use conditions, it can be shown that small openings or gaps in clothing markedly increase the rate of moisture and heat transfer, especially in moving air. In other words, in an assembly of clothing, openings at the arms and legs, open collars, or short sleeves may well mask any differences in insulation or cooling effectiveness of various clothing assemblies.

I dislike complicating our problem any more, but I am compelled to point out still another difficulty. In studies of blends, the assumption is generally made that the experimental fabrics being studied are identical and the only variable is fiber content. In actual practice, this seldom turns out to be the case. Different fibers spin and weave differently, and the fabrics respond in different ways to finishing, such as fulling or napping. To illustrate further, let us consider for a moment what happens in studying some wool type fabrics in which the percentage of synthetics is varied in a systematic manner. One quickly finds that the geometrical order of the fibers in the yarn may greatly affect the results. At one extreme wool fibers exhibit three-dimensional crimp and the fibers encompass a wide range of diameters and length. In the yarn, the fibers and fiber segments are far more randomly distributed than in a comparable yarn of synthetics. Fulling increases the randomness even further. As a result, the wool fabric tends to be lofty and hairy. At the other extreme, the synthetics are relatively uniform in length and cross section and tend to conform to the yarn pattern more closely. Fulling does not occur so that the orderly state of the fibers is not disturbed.

It is obvious then, that in producing wool-like blends, it may be necessary to alter several variables in order to produce a series of fabrics of somewhat comparable structures and this then makes precise comparisons very difficult.

These are a few of the problems of blends. It is extremely comforting to know that in spite of all these difficulties and complexities, many outstanding blends have been brought into use and it doesn't require any fortune teller to predict that the number and quality of blends will be increased. Much effort will be directed towards improvement since the industry has already seen the adverse effects of poor blending and inferior merchandise.

To date, as pointed out earlier, most of the efforts have been along the lines of producing improved fabrics of existing design. This is only natural in an industry where excellent fabrics have been developed and produced for thousands of years. But should we continue to strive towards making every fiber and fabric like every other one? It has always seemed somewhat of a paradox that we strive to deluster rayon and other synthetics and work hard to increase luster in cotton and wool. It is common practice to talk of wool-like fabrics. Recently I was most amused when a person high up in the rayon industry showed me a sample of cloth made of texturized nylon. When I asked him what, in his opinion, was the outstanding contribution of texturized yarn to this particular fabric, he replied, "it gives it a wonderful cottony feel."

With a better understanding of the potentialities of blending, it will become intriguing to think in terms of radically new fabrics of greatly improved functionality. It becomes even more intriguing from the point of view of the over-all textile industry to ponder the effects of such developments as one means of ultimately gaining for the industry a larger portion of the consumer's dollar.

Finishing of Fabrics*

Hector C. Borghetty†

MODIFICATIONS of fibers and fabrics by mechanical and chemical means constitute the final operations to which textiles are subjected. The original purpose of finishing was to enhance the appearance of fabrics and render them more merchandizable. In recent years the advances in finishing operations have been notable and the increase in chemical finishing has contributed greatly to the embellishment of fabrics, to increased wearability, and to a multitude of special effects that render the materials more versatile and adaptable to special garment uses.

Much of the ingenuity of the textile industry, formerly evidenced in intricate spinning and weaving machinery and in speed of operations, has been transferred to variations in hand obtainable during the finishing processes. The surprising "come-back" of cotton fabrics this season has been achieved by novel finishing combined with advanced styling. King cotton has reacted very effectively to the highly glamorized miracle fibers and has successfully re-established itself as the most durable, the toughest, and the most adaptable fiber. It has also given finishers the opportunity of proving that the textile industry is far more chemically minded than many outsiders believe it to be.

One of the most important events of the decade has been the entrance of the majority of the very large chemical manufacturers into the textile industry; this, coupled with the introduction of several new and very ingenious synthetic fibers, means that a vastly greater number of scientists will investigate, contribute to, absorb, and amalgamate the technology and trends of the industry. Up to the present time many of the standard practices of the industry have been studied and considered satisfactory. Many well defined textile operations perfected tediously over the centuries have been found to be basically sound from a scientific point of view. Science, therefore, having overtaken the technology of textile processing, is finally in an excellent position to predict new approaches, create new reactions, modify existing techniques, and introduce new building blocks. The greater part of the efforts of chemical companies during the past 14 years has been devoted to competitively achieving equality with the inventions made prior to World War II. This lag has given the textile plants ample opportunity to increase their laboratory staffs, and to train chemically minded personnel able to utilize new processes and inventions. Chemically speaking, textile technology is, therefore, in a very good position today compared to some years ago.

An example of amalgamation of knowledge, points of view, science, and salesmanship is being offered us right now in the attempts to establish the future position of the newer synthetic fibers in the minds of the consumer. If the advertising were fully successful there would be a delay of several years before plant production could meet the demands created. Some of the new fibers have, meanwhile, established specialty uses and are also contributing to improvements of many fabric blends and constructions. An example of successful use is that of a nylon addition to acetate-viscose blends to improve resistance to severe wear.

Many of the newer synthetic fibers were introduced to the market by stimulating a direct consumer demand; this resulted in a great deal of interest by the public with consequent pressure on the mills to introduce many fabrics without appropriate field testing. The variety of fabric combinations possible is almost endless and many types are not acceptable, popular, or satisfactory. Some of the fibers found an immediate market in white shirts and other undyed garments. Some straight spun constructions and many combination fabrics, however, did not fulfill claims expected of miracle fibers. The advertising had shifted to show how fiber *X* and *Y* could be blended to give all advantages formerly claimed for *X* or *Y*. Unfortunately, some of the disadvantages that would result by complications in dyeing and finishing had not been anticipated or sufficiently well investigated. This explains the recent more conservative appraisal of fabrics made by blending hydrophobic fibers with the water absorbent natural fibers.

* Presented at the Annual Meeting of Textile Research Institute in New York City, Nov. 13, 1953.

† Textile Chemicals Department, Rohm & Haas Company, Philadelphia, Pa.

Difficulties encountered in finishing plants indicate that there will be further readjustment of many fabric styles and compositions and that some of the new fibers and fabric constructions destined to give multi-purpose effects and to eliminate finishing operations will require extensive field testing and modification. There is already an indication that a good deal of success is being obtained by utilizing the newer fibers as components in wool, cotton, and rayon fabrics.

Many textile finishers retrenched temporarily in face of the barrage of new fibers and blends that could simply be heat-set to give dimensional stability and which were in themselves water resistant, wear resistant, and "multi-proof"; realization, however, that the new fabrics also brought new and difficult problems has now led to a reorientation in the finishing of the older fabrics. Instead of curtailing the activity of the finishing industry, the new fibers have thus stimulated the imagination of chemists, converters and finishers, and brought about the wide spread application of specialty chemicals to cotton, rayon, acetate, and nylon, and the improvement in abrasion resistance of rayon and acetate blends. Modifications of fiber properties at the fabric stage mean, furthermore, that textile inventories are subject to better and cheaper control.

The outstanding quality of the newer fibers, "hydrophobicity," meant quick drying, low swelling, and good dimensional stability of the resultant fabrics, but it also meant poor water absorption of the dyestuff and finishing baths, and high static effects. The deviations from physical properties of the natural fibers meant high pilling, claminess, and consequently bad sales appeal for many uses.

The water resistant property of the miracle fibers was soon countered by the extensive use of water repellents on rayon and acetate. This in turn led to the introduction of reactant type water repellents and of silicones that could be applied simultaneously with reactant type resins to give crush resistance, shrinkage control, and water repellency in one treatment. Hydrophilic fibers of good water absorbency such as rayon and to a lesser extent of the partly hydrophilic acetate, can be handled very economically, rapidly, and without undue precaution on standard textile equipment; whereas, the new fibers, alone or in blends, present problems that still require processing modifications.

The ease of reactivity of cellulosic fibers with thermosetting resins soon brought about the successful utilization of two novel type modified urea formaldehyde resins capable of reacting with cotton, rayon, and to a lesser extent, with acetate. These resins give assurance that the hydrophilic fibers can continue to be handled under normal plant processing conditions and then rendered more hydrophobic to match many of the miracle fiber properties. This fact is destined to become a very important consideration in the competitive situation of fabric construction today.

The formulating procedures to accomplish these results are well established, although not widespread. The control of fiber swellability with resultant increase of fabric stabilization also leads to increased dyestuff washfastness and the broad horizons of dyeing and finishing in one operation. Reactant type resins not only seal the cellulose hydrophilic groups by "zippering up" the skin of the fiber, but can be employed to insolubilize dyestuffs possessing appropriate reactive sites. This has recently been proven possible with acetate by selecting dyestuffs suggested by Fortress, Sprague, and Stoll of Celanese at the 1953 Annual A.A.T.C.C. Convention. When used in conjunction with copper dye fixatives the reactant resins make possible more economical handling of washfast fabrics. Let us see how reactant resins differ from standard types.

Thermosetting resins can be classified as follows:

(*A*) *Urea formaldehyde or melamine formaldehyde.*—Available predominately as monomers. This type readily penetrates cellulosic fibers and can then be cured and condensed to give cross-linked polymers capable of creaseproofing or stabilizing. These resin forming materials are not actually beneficial to acetate, but are used on combinations of rayon and acetate because of their excellent effect on the former fiber. They are not satisfactory for nylon, Dacron, or acrylic fibers. Some are also of poor storage stability.

(*B*) *Urea formaldehyde syrup resins.*—Similar to the above, but of greater condensation, which results in linear polymeric resins. Satisfactory for surface effects they are used either alone or in conjunction with type *A* to give crisp washfast finishes. They cannot be classed as crush resistant resins although when cured they also become cross-linked. Not satisfactory on acetate, they often possess good adhesion to nylon. They all have good storage stability as chemical products.

(*C*) *Polyfunctional modified urea formaldehyde monomeric types.*—Characterized by high storage stability and ability to penetrate cellulosic fibers as in

type *A*, but also to react with rayon to give superior stabilization, but less crushproofing effect. Satisfactory on blended fibers of rayon acetate and nylon. They also give excellent durable firmness on acetate and unusually good adhesion to nylon. Although the effect on nylon is a surface one, the good adhesion and flexibility do not detract from the elasticity and crushproofness of this fiber.

(*D*) *Difunctional modified urea formaldehyde reactant types.*—Characterized by outstanding storage stability, high reactivity on rayon, crush resistance on rayon and cotton, unusual durability of effects, coupled with greatly improved chlorine resistance. Useful on acetate fibers to penetrate and react, thus able to seal the hydrophilic portions of the fiber and render it more hydrophobic, with consequent good stability to washing above 120°F. On nylon the effect is external and not noticeably advantageous because the material does not form surface resin and thus imparts no hand build-up.

A large volume of the blended fabrics used today are based on spun fiber combinations of rayon and acetate. The rayon component, after resin treatment, gives dimensional stability to the fabric and good glazing resistance. The acetate component gives better hand, superior draping qualities, and increased wrinkle recovery. The best fiber balance is customarily in the 50/50 range. Fabrics of 100% spun acetate are rare because of poor glazing resistance and hot iron sensitivity; all spun rayon fabrics are produced satisfactorily but often suffer from poor wearability and low abrasion. Combinations of 40/40, together with 20% nylon, have shown remarkable increase in wearing properties and satisfactory abrasion resistance. Practically all constructions of 50/50 are marketed in resin finish to make them acceptable for slacks, suitings, and sport shirtings, where physical properties such as strength, wrinkle recovery, low pilling, good washability, perspiration resistance, and durability are of importance.

The low initial wrinkle resistance of the rayon is remarkably enhanced by the use of the resin treatment. Care must be taken to deposit the correct amount of resin for each fabric to give the desired shrinkage and wrinkle resistance without excessive loss in abrasion resistance. The acetate component, because of the low water absorption, picks up less (about ¼) of the total resin ratio and, unfortunately suffers somewhat in all physical properties during the curing operation. The resin picked up by the acetate is composed of a large amount of poorly adhered, unfixed resin, which will easily flake off the fabric and imparts the harsh, gritty feel sometimes noticed on materials that have not been afterwashed. Some surface resin film is also retained by the fiber and imparts firmness, which often-times is considered objectionable.

Investigation of resin distribution on the component fibers of the blended fabric is just now being given serious study by textile chemists. Too much importance has been attached in the past to the amount of resin on the total fabric; as long as it was in sufficient quantity to give crush resistance, little consideration was attached to the resin on the acetate component. It is well known that acetate in itself gives good wrinkle recovery; whereas, the viscose fiber alone has very low initial wrinkle resistance. After resin treatment the wrinkle resistance of the viscose actually surpasses that of the acetate portion, which is often-times decreased by recovery angles of 10°–20°. A resin that will increase the acetate recovery instead of decreasing it, would be a boon to the industry because it would then be possible to utilize small amounts of resin on the viscose. It is well known that an excess of resin on the viscose lowers the abrasion resistance and tensile strength, with subsequent reduced wearability of the garments. Better distribution of the resin on the two fibers would mean less total resin on the viscose, slightly less wrinkle recovery on this fiber, but improved wearability. This lower wrinkle recovery would be compensated for by the increased contribution of the acetate fiber so that the total fabric would be up to specifications.

It is now known that reactant type resins when applied to acetate will give good stabilizing effect to the fiber. Their tendency to lower abrasion resistance can be offset by the addition of water repellents of the reactant type that contain long fatty chains.

Whenever blends of other fibers are introduced, it becomes even more important to consider the effect of the resin on this new component as well. The majority of resins at our disposal today cannot be considered satisfactory for use on nylon. They also show very poor adhesion on Dacron, Dynel, Acrilan, and Orlon. It, therefore, becomes extremely important to decide whether the introduction of a new fiber brings a further complication to the aforementioned resin distribution problem. If the new fiber can be used in sufficient quantity to impart the desired wrin-

kle resistance effect, we could dispense with the use of the resin treatment. Experience has shown, however, that in order to eliminate resin treatment the amount of hydrophobic fiber necessary runs as high as 80% in a combination fabric with rayon. It is for this reason that many fabrics are still being produced with standard viscose-acetate combinations and that the new wrinkle resistant synthetic fibers are not being added excepting for improvements in wearability. Nylon, when used as a third component, up to 20% does not interfere with standard thermosetting resin treatments.

Orlon can be used to impart wrinkle resistance to cotton. The minimum quantity necessary of 50% substantially raises the cost of the fabric and has led to the renewed interest in crush resistant 100% cotton by the use of thermosetting resin treatments. Dacron, the new polyester fiber made from terephthalic acid and ethylene glycol, has high wrinkle resistance, high strength, and can be used as a straight fiber for shirtings or in conjunction with wool or rayon to improve the wrinkle resistance and strength of the fabrics. It has been more successful in combination with wool than with rayon. The majority of fabrics today composed of Dacron and wool are finished by standard wool procedures, which means an emphasis on the mechanical finishing operations with practically no chemical finishing operation. Fulling, decating, calendering, napping, and shearing are the operations to which wool fabrics are subjected, and we find these operations given to combination fabrics of wool and Dacron as well as wool with other synthetics.

The use of resin stabilizing treatments on wool is still relatively small, but promises to become more important with the demands made by the consumers today. Stabilizing treatments based on chlorine are used extensively for wool fabrics, but are not used on combination fabrics of wool and synthetics. The acrylic fibers such as Orlon (a 100% acrylonitrile type), Acrilan (a copolymer type acrylic), Dynel (a copolymer of acrylonitrile and vinyl chloride) are all characterized by wool-like bulky qualities. They have high weather resistance for outdoor use, are chemically inert, and have excellent wrinkle resistance, good resiliency, and impart high dimensional stability to fabrics. They could be used in conjunction with rayon and cotton, but extensive use of such combinations have not yet been encountered.

Vicara, a protein derived from the zein in corn, is a wool-like fiber recommended for use in rayon or wool blends. Celcos is a partially saponified acetate fiber, while Fortisan is derived from a fully saponified acetate resulting in a highly oriented cellulose. Both of these are not extensively used in blends at present. Saran, a vinylidine chloride fiber is wool-like and is being tried for carpet use.

Nylon is not considered one of the newer hydrophobic fibers because it has a well established place in the textile field and is expanding rapidly, based upon successful uses. As a matter of fact, it possesses some of the best qualities of the hydrophobic group and promises to become more important to increase the tensile strength, wearing qualities, and dimensional stability of fabrics. To improve the wrinkle resistance of rayon and cotton, as well as the dimensional stability, requires 40% to 50% nylon.

In this presentation we have not dwelt upon any of the finishing procedures because we felt that they are so well established and so few changes have taken place that nothing could be added excepting of a detailed nature. There is a tendency to stream-line operations. The use of water soluble polymers that lend themselves to fixation by reactant resins and thus impart modifications of hand are materials that are going hand in hand with newer techniques. The use of softening agents that assist in fabric properties have only recently been fully understood and utilized. The dry heat setting equipment so universally utilized for fabrics of nylon and Orlon is not necessary for combination fabrics. Wet heat setting in open form as a prescour is carried out to avoid wrinkling of fabrics composed of acrylic fibers.

Progress in the Dyeing of the Newer Synthetic Fibers*

Paul J. Choquette†

Introduction

Realistic thinking has been the current trend in the development of fabrics from the newer synthetic fibers. Industry has come to realize that a great deal of research and development must be carried out before a miracle fiber is converted into a miracle fabric. Ultimate success depends upon meeting end-use requirements which means consumer satisfaction. Fine progress is being made. Technologists are studying fiber properties and their relationship to results produced in finished fabrics. The scope of this work has been clearly indicated by the excellent papers presented by the previous speakers. Industry has also come to realize that the coloring of these new fibers by practical methods and in shades which meet end-use requirements is of as much importance for success, as is the attainment of improved physical properties. As an example, witness the increasing demand for fabrics produced from cellulosic fibers, cotton or rayon, with the advent of fast-color dyeing. Fabrics produced from the newer synthetic fibers are expected to be long-wearing, stable, and washable. It is to be expected that such quality merchandise must possess outstanding fastness properties. Excellent progress has been made in meeting many of the requirements of dyeing the newer synthetic fibers, and further improvement may be anticipated. This has been a result of fine cooperation of fiber, dyestuff, and auxiliary-chemical producers with dye-application specialists, research chemists, and the dyers and finishers of the textile industry. It is apparent that no simple solution will be available to meet the requirements of the variety of fibers now being produced or which may become available. It will continue to be necessary to screen the various classes of dyes and to consider or utilize the newer methods of dyeing. As the facts of these dye application studies are made available to researchers in dyestuff syntheses, it is expected that present ranges of dyes will be extended to meet particular end-use requirements. Considerable progress has already been made in this direction and may be expected to continue. It will be my purpose to discuss these new concepts of dye application and their utility in dyeing some of the newer synthetic fibers now being utilized by the textile industry. In addition, the influence on dyeing methods of fiber modification by the manufacturer, as well as the trend to the use of fiber blends will be surveyed.

The properties that make the newer synthetic fibers so valuable have contributed to the difficulty of dyeing. Their hydrophobic character, resistance to chemical agents, limited swelling properties, and smooth surfaces all make difficult the penetration and retention of dye particles. Higher temperatures or the use of carriers have been found necessary to diffuse dye into many of the newer synthetic fibers. It is believed that such methods will continue to be required and in fact have already attained the status of commercial production.

High-Temperature Dyeing

The degree to which individual fibers respond to higher dyeing temperatures varies. In some cases, this temperature may be limited by excessive shrinkage or a harshening of the fiber. In general, however, even in those cases where dyeing is carried out on conventional equipment, the importance of obtaining temperatures above 205° F is emphasized and advantages are noted for temperatures up to 212° F. For this reason, the use of closed jigs or kettles which permit temperatures up to 208° to 210° F is recommended. The value of this technique in the dyeing of nylon has been well proven, and it is even more important for the more hydrophobic fibers. High-temperature dyeing is, however, normally understood as the operation carried out in closed pressurized equipment where temperatures up to 250°F are obtained. The Thermosol Process utilizes dry heat treatments up to 400°F.

* Presented at the Annual Meeting of Textile Research Institute in New York City, Nov. 13, 1953.

† Coordinator of Research, General Dyestuff Corporation.

TABLE I. HIGH TEMPERATURE DYEING

Fiber	Method of Dyeing	Temperature	Remarks
Dacron	Disperse dyes Diazotizable disperse dyes	250°F	Excellent color value and penetration
Orlon 81	Selected basic dyes	250°F	Excellent color value and penetration
	Vat colors	250°F	Improved color value and penetration
Orlon 42	Acid colors by cuprous-ion method	230°F	Larger range of dyes and better wet fastness
	Vat colors	230°F	Bright shades of excellent fastness
Dynel	Disperse dyes	215°–220°F	Shorter dyeing period Improved penetration
Acrilan	Chroming of acid chrome colors	230°–250°F	More rapid and complete chroming
	Vat colors	230°–240°F	Improved color value and penetration
Wool	Acid and chrome colors	225°F	Shorter dyeing time
Nylon	Neutral-dyeing premetallized dyes	250°F	Improved penetration, outstanding wash fastness

Table I indicates temperatures which have been utilized on various fibers to obtain particular end results.

The value of heat in promoting the dye penetration of Dacron polyester may be illustrated by pressure-steaming (40 p. s. i. for 30 min.) a dyeing first carried out at conventional temperature (208°F). From the appearance of the dyebath good exhaustion had been obtained but the shade was weak. After steaming and as a result of fiber penetration, approximately 15% increase in shade was noted. Fastness properties of the steamed patch were excellent. The Thermosol Process produces fiber penetration through the use of dry heat up to temperatures of 400°F [7]. This method has been considered for the continuous dyeing of filament Dacron and utilizes the steps of padding, drying, heat setting, and washing. The Barotor Pressurized Fabric Dyeing Machine permits the batch dyeing of piece goods at temperatures of 250°F [3]. The Uxbridge Finishing Co. machine was designed to handle piece goods continuously at 250°F [14]. Molten-Metal Dyeing offers interesting possibilities [11]. Other machines are in operation or development for the pressure dyeing of knit fabrics, hosiery, and for the continuous scouring, dyeing, and setting of nylon hosiery.

Dacron

Dacron polyester fiber is an outstanding example of the improved penetration and color value obtainable at elevated temperatures. This fiber can be dyed to the same depth as acetate and even heavier than nylon with disperse dyes, provided that penetration and sorption of the dye by the fiber can be realized. One method of accomplishing this is by dyeing at 250°F. It is necessary to select the disperse colors, inasmuch as fastness to light may not be comparable to that obtained on acetate or nylon. The number of suitable dyes has been extended, particularly in the anthraquinone class, so that a range is now available which meets the fastness requirements of the suiting trade. Dyeing is normally carried out on stock, top, or yarn under pressure in closed circulating machines. Navy blue and black shades may also be produced through the use of a diazotizable disperse dye and developer. Dyeing of the two components is carried out at 250°F, fol-

lowed by diazotization at atmospheric pressure and lower temperatures (140°–180°F). Coupling within the fiber proceeds simultaneously. It may be well to mention at this time one problem which has given some trouble in pressing of Dacron piece goods. If temperatures up to 320°F are utilized, poor sublimation fastness (marking off on white fiber) of dark shades may be noted. This will vary with the selection of dye and method of application. In general, no difficulty is encountered in properly dyed light to medium shades. For dark shades pressing temperatures of 250°–260°F should not be exceeded in order to minimize this trouble.

Orlon

Dyeing of the acrylic fibers is also improved in many cases through the use of higher temperatures. Orlon 81 acrylic fiber has poor affinity for selected basic or vat dyes when applied at temperatures under 212°F. Dyeing at 250°F yields excellent results in both cases. Although Orlon 42 acrylic fiber dyes more readily than Orlon 81, nevertheless, a wider range of acid dyes of improved fastness to wet processing is available when applied at 230°F by the cuprous-ion method.

Acrilan

Acrilan acrylic fiber is normally dyed with acid or chrome colors at conventional temperatures [13]. Experiments have shown that in the case of chrome dyes, elevated temperatures (240°–250°F) speed up and complete the chroming more readily. A complete range of vat dyes may be applied to Acrilan stock at temperatures of 230°–240°F to yield shades of outstanding fastness properties. It is of interest to note that certain vat dyes are faster to light on the Acrilan fiber than on the cellulosic.

Dynel

Selected disperse, neutral-dyeing premetallized and acid dyes applied by the cuprous-ion method meet many of the end-use requirements for Dynel. These are normally applied at temperatures of 205°–208°F. With disperse dyes, shorter dyeing time and improved penetration are obtained when temperatures of 215°–220°F are utilized [5].

Wool, Nylon

I have included wool and nylon in the dyeing chart because they too illustrate the value of high-temperature dyeing. Shorter periods of time are needed when wool is dyed at 225°F. Good penetration and fastness are obtained without impairing the physical properties of the fiber [8]. Neutral-dyeing premetallized dyes applied to nylon at 250°F yield shades of outstanding fastness properties [10].

Chemical Auxiliaries

Carriers

Chemical auxiliaries have proven to be valuable tools in dyeing the newer synthetic fibers. Of particular importance has been the development of the carrier principle. A carrier may be defined as a chemical assistant of limited water solubility which promotes penetration and sorption of dye. This action is frequently accompanied by a swelling of the fiber, but this is not always the case. Experiments indicate that monochlorobenzene, which is very efficient as a carrier for disperse dyes on Dacron, does not swell the fiber. This carrier has the property of producing a layer of concentrated dye solution around the fiber. This intimate contact promotes absorption and penetration. The relationship between dyeing and carrier action in the case of Dacron subscribes to the solid-solution theory. A disperse dye which is readily absorbed by the fiber, will exhaust much less onto the fiber if a water-solubilizing group is introduced into the dye molecule. The dye is more attracted to the water of the dye medium and stays in solution. Effective carrier action may be impeded in a similar manner if a mutual solvent or emulsifying agent is added which overcomes attraction for the fiber by increasing the solubility of the carrier in the water medium. This effect may be illustrated in the case of n-Butanol which at concentrations of 3 to 5 ozs. per gallon of dyebath is a very effective carrier in dyeing acetate with vat colors. In this case, reduction and dyeing without saponification of the acetate are accomplished through the use of an organic alkali and sodium hydrosulphite. The addition of a mutual solvent such as Cellosolve to the dyebath stops the carrier action and yields a poor color value. In a similar manner, it is possible to produce such stable dispersions of monochlorobenzene as to impede its carrier action. This selectivity between fiber, carrier, dyestuff, and dyeing medium is characteristic of the problem, and of the hundreds of possible carriers tried, only a limited number have proven of practical value. The ideal carrier should

be cheap, perform its work, and then be easily removed from the fiber after dyeing. Certain carriers if not removed from the fiber, adversely affect light fastness.

Carrier dyeing has been of particular value for coloring Dacron polyester fiber (see Table II). It has made possible the dyeing of stock, top, or piece goods on conventional equipment. Selected disperse dyes are utilized and permit the production of shades meeting men's wear fastness requirements.

The monochlorobenzene method is limited to application in closed circulating machines on raw stock, top, or yarn, all of which have been successfully dyed by this method. It is essential that suitable ventilation be available, inasmuch as monochlorobenzene is somewhat toxic. This solvent is normally utilized as a dispersion produced with a sulfonated oil, but in closed machines sufficient dispersion is obtained by mechanical agitation alone. Dyeing with disperse (acetate) colors in the presence of this carrier is carried out at 185°F, following which the temperature is raised to 210°F to remove the carrier by steam distillation. Chlorinated benzenes produce complete penetration of the fiber, and disperse dyes applied in this way exhibit excellent fastness to successive mill processing. Finished goods meet men's wear fastness requirements. In the use of p-phenylphenol, o-phenylphenol, or benzoic acid these carriers are first uniformly distributed through the material as the wear-soluble sodium salt (dissolved in caustic soda) and then reprecipitated as a fine dispersion by addition of acid. Methylphenylcarbinol or Ketosol Solvent 75 are sufficiently water soluble to be utilized directly at the recommended concentrations. Reports from the trade indicate that these two carriers offer promise with selected disperse dyes. Since Ketosol Solvent 75 is more rapid in its action and may harshen the fiber, a lower concentration is recommended. O-phenylphenol is preferably used over p-phenylphenol where maximum fastness to light is required, inasmuch as it is more readily removed from the fiber. An alkaline scour after dyeing is recommended for removal of these carriers when necessary.

Carrier techniques have been utilized to a more limited extent in the case of the acrylic fibers. Increased color values are obtained in dark shades on Dynel with acid colors applied by the cuprous-ion method with the assistance of 2% to 2¼% p-phenylphenol (owf). This amount should not be exceeded if shrinkage of fiber is to be avoided. It has also been observed that certain disperse dyestuffs in the yellow range (dyes containing phenolic groupings) act as carriers for acid colors which are applied by the cuprous-ion dyeing method. In this case a single dyebath is utilized for both classes of colors. Improved color values are obtained with disperse dyes on Acrilan acrylic fiber through the use of 6% to 8% p-phenylphenol (owf). When this carrier is employed, the lightfastness must be checked to make certain that it has not been impaired by the presence of unremoved carrier.

Time will not permit a detailed discussion of the importance of other auxiliary chemicals in the dyeing of the newer synthetic fibers. Selected anionic, nonionic, or cationic materials perform roles in scouring, as dye assistants, in promoting levelling, as retarding agents to improve penetration, as assistants and stabilizers of dyes utilized in dyeing of blended fibers. Typical examples will be cited under particular problems that are to be discussed.

TABLE II. TYPICAL CARRIERS FOR DACRON AND THE CONCENTRATIONS RECOMMENDED

Solvent	Raw stock, tops or yarn on the package machine	Closed jig or kettle
monochlorobenzene‡	20% owf*	Not suitable
p-phenylphenol	1–6% owf	2–9% owf
o-phenylphenol	2–10% owf	2–10% owf
benzoic acid	2% ows†	2% ows
methylphenyl carbinol	2% ows	2% ows
Ketosol Solvent 75	1% ows	1% ows

* owf, on wt. of fiber.
† ows, on wt. of solution.
‡ A patent for the monochlorobenzene method has been granted to General Dyestuff Corporation.

Special Methods of Application

Cuprous-Ion

An interesting example of the special methods which have been developed for dyeing the acrylic fibers based on acrylonitrile has been the cuprous-ion method [4]. If such fibers are exposed to cuprous ions they have improved affinity for selected acid and direct colors. Presumably, cuprous copper forms a complex with the nitrile group of the fiber and thereby imparts an affinity for dyes containing acid groups. In general, acid dyes containing monosulfonic acid groups are best suited for producing good dyeings. The reducing agent should have a reduction potential sufficient to reduce cupric copper to the cuprous state

but not to affect the dye nor produce free copper. This method finds particular interest for dyeing Dynel and Orlon 42. The significance of this method may be judged by the observation that certain acid dyes which produce dyeings of inferior fastness to washing on wool or nylon, yield shades of good fastness to washing and to light on Orlon 42 when applied by the cuprous-ion method. For application to Dynel, copper sulfate may be reduced with either zinc sulfoxylate-formaldehyde or hydroxylammoniumsulfate, and dyeing is carried out at 208° to 212°F. Orlon 42 may be dyed at temperatures up to 230°F to obtain a broader selection of dyes of improved wet-fastness properties. Other reducing agents utilized are sodium bisulfite and glyoxal. Instrumental measurement of reduction potential is a valuable tool in controlling this method of dyeing [2]. To summarize, the cuprous-ion method has permitted the dyeing of dark shades meeting the needs of fastness to wet processing as well as to end use requirements.

Developed Azo

The use of developed azo combinations for the production of bright orange, scarlet-red, and maroon shades on Dacron of very good fastness to washing and to light necessitated the use of special techniques. It was found that the fiber would absorb dispersed beta-hydroxynapthoic acid as well as certain selected diazotizable bases, such as p-chloro-orthotoluidine. In practice the two components are simultaneously exhausted from one bath at 205°F. After rinsing, diazotization is started cold and gradually raised to 180°F (5% sodium nitrite, 5% sulfuric acid, 66° Be', owf). The dye is produced within the fiber.

After-Treatments

The principle of introducing the components of a dye within the fiber for later insolubilization seems to offer promise of further development. One of the problems in such a process is the difficulty of obtaining complete penetration through a cross section of the fiber with the after-treating agent because of the hydrophobic character of the fiber. Fortess has pointed out the possibilities in the case of acetate of chelating amino and hydroxyl groups by means of cupric ion or of aliphatic hydroxyl groups which may be reacted with reactive resins [6].

Modification of Fiber

The dyeing properties of fibers may be greatly altered by a change in chemical constitution or by the addition of a copolymer to the fiber in manufacture. An outstanding example is Orlon 42, which is more dyeable than the former Orlon 41. Selected disperse dyes color Orlon 42 in light to medium shades of good fastness to light and washing. Conventional temperatures of 205°–210°F are utilized, whereas, in the case of Orlon 41, temperatures of 250°F were required in order to obtain penetration. In addition, selected basic dyes may be applied to Orlon 42 at conventional temperatures to produce a range of shades of good fastness to light and to washing. This increase in dye affinity has necessitated modification in the method of application of acid colors by the cuprous-ion method. In stock dyeing precautions have to be taken because of shrinkage. The temperature of dyeing is reduced to 230°F as compared with 250°F for Orlon 41. The rate of dyeing is further slowed down by the use of retarders and a lower pH [9].

Acrilan acrylic fiber contains a copolymer, which gives it affinity for acid colors. These dyes are applied at the boil with the assistance of 2% to 4% sulfuric acid (owf). The new type Acrilan CN-33 has increased affinity for these colors and thereby improves the scope of union dyeing with wool.

Union Dyeing

Fiber blending has been the current trend in the use of the newer synthetic fibers. In this manner, the new fiber adds its advantages to the accepted inherent value of the older and established types. Blends of Orlon 42, Dacron or Dynel with wool, cotton, or rayon have been of particular interest. Attractive fabrics have been produced where the wool, cotton, or rayon was dyed to leave the newer synthetic fiber white. Problems in union dyeing solid shades with wool in the piece heightened interest in stock dyeing. In this procedure, the fibers are dyed separately and then blended to produce solid shades. Stock dyeing, however, presents manufacturing limitations and an inventory problem due to the difficulty of predicting shades which will sell. Volume production favors dyeing in the piece, and as a result this subject is being actively developed.

Orlon 42, Wool, Cotton, or Rayon

Orlon 42

Attractive heather effects have been produced by dyeing wool, rayon, or cotton to leave Orlon 42 white. Selected level-dyeing acid, chrome, and neutral-dyeing premetallized colors are utilized for the wool. The quality of the white obtained on the Orlon 42 is improved with certain acid and chrome dyes by an addition to the dyebath of 2% of an alkylarylsulfonate assistant coupled with omission of Glauber's salt and the use of formic or a combination of acetic and formic acids. In the case of the cotton or rayon selected direct or direct-after-treated colors are utilized.

Solid shades may be produced on Orlon 42-wool blended yarn or piece goods through the use of selected basic colors for the Orlon 42 and selected acid dyes for the wool. The use of 4% (owf) of 28% acetic acid in the bath keeps the basic dye off the wool and the presence of 2% (owf) of cationic assistant of the type produced from an active organic compound condensed with a polyethyleneoxide chain prevents mutual precipitation of acid and basic dyestuff and assists penetration. A water-soluble polyethylene ether of a fatty alcohol has also been recommended for this purpose. Selected disperse dyes may likewise be employed in combination with basic dyes for dying the Orlon 42.

The dyeing of Orlon 42-rayon or -cotton yarn or pieces is best carried out by a two-bath procedure where the Orlon is first dyed with disperse or basic dyes. If the cotton or rayon is stained sufficiently to affect the final wet fastness or fastness to light, it is cleared by a light scouring or by a special permanganate-bisulfite method for clearing the rayon. After the rayon has been cleared, it is brought up to shade in a fresh bath with selected direct colors.

Dacron With Wool, Cotton, or Rayon

Dacron wool blends are finding increasing trade acceptance. Selected acid colors may be utilized to dye the wool and to leave the Dacron white. We have already discussed the dyeing of 100% Dacron stock or top, which may then be blended with dyed wool stock. The monochlorobenzene method permits the dyeing of Dacron-wool blended top to meet wet processing and men's wear end use fastness requirements. Disperse dyes are used for the Dacron polyester fiber and must be selected on the basis of those that stain wool least. The staining of wool is also minimized by the carrier, which tends to keep the color off the wool. The dyeing procedure is similar to that utilized on 100% Dacron, the wool being only slightly stained. The wool is then brought up to shade with suitable dyes by conventional methods.

Encouraging progress has been made in the dyeing of Dacron-wool fabrics in the piece. This problem is more difficult than dyeing stock or top in closed circulating machines. Newly developed disperse dyes, particularly of the anthraquinone types, have helped, but the method is still hampered by the limited number of dyes that stain wool a minimum. Excessive staining of the wool by disperse dyes may adversely affect the fastness to light and to perspiration. Individual shades should be screened in terms of end use. Emulsified monochlorobenzene or trichlorobenzene (10%–20% owf) have been considered as carriers for this work, but appear to be excessively volatile for application on dye kettles. They also require special care in ventillation because of toxicity. Whereas trichlorobenzene, because of its higher boiling point, is less volatile than monochlorobenzene, it is also more difficult to remove from the fiber. O-phenylphenol (10%–20% owf) has been most commonly utilized as a carrier. The Dacron-wool piece goods are first uniformly impregnated with the sodium salt (Dowicide A) at a temperature of 70° to 80°F. Care must be taken to assure complete solution of this material, a slight additional portion of caustic soda being added when required. Stains on the material will result if spotted with carrier. The o-phenylphenol is next precipitated as a fine dispersion by an addition of acetic acid. Acid (pH) as such apparently does not influence the carrier action but in the presence of wool the bath should only be faintly acid—*i.e.*, at a pH value of 5–6. Disperse, acid-chrome or neutral-dyeing premetallized dyes are next added. The temperature is then gradually raised as close to the boil as possible (208°–210°F). Dyeing is carried out at that temperature. Chroming when required is carried out in the same bath by cooling to 180°F in the presence of a further addition of 1% (owf) of 56% acetic acid. The material is then rinsed, scoured with nonionic detergent at 180°F, rinsed, and dried. This scouring is important to remove as far as possible any disperse color that is staining the wool. Control of patching for shade is very important and should simulate the after-treatments which the fabric will receive. Particular care should also be taken to select dyes that

fade in tone on both the Dacron and wool. If the dyes on one component of a blend are much faster than or change differently in tone from those on the other component, an undesirable effect may result upon exposure to light.

Dacron with Cotton or Rayon

The dyeing of Dacron-cotton or Dacron-rayon materials with commercial colors offers no particular difficulties. Selected direct colors may be employed to dye the cotton or rayon and to leave the Dacron white. For solid shades, direct or direct-after-treated dyes are utilized for the rayon with disperse dyes for the Dacron. The use of a carrier is required for medium to dark shades. For Dacron-cotton or Dacron-rayon piece goods, such as shirtings where better fastness to washing is desired, the cellulosic fiber may be vat-dyed continuously followed by dyeing of the Dacron with selected disperse dyes in a separate bath. The reverse procedure whereby the Dacron is first dyed followed by continuous dyeing of the cotton or rayon with leucoesters of vat dyes may also be utilized. Experiments would also indicate that vat colors may also be used by this method, since selected disperse colors on the Dacron resist reduction in the short time factors utilized in continuous dyeing. Simultaneous dyeing of Dacron-cotton to the same shade by a continuous operation which requires padding has presented difficulties because of unequal absorption of color by the two fibers. Since pick-up on the hydrophobic Dacron is much less, it dyes lighter. A vat acid procedure has been considered for this purpose [12]. The Dacron-cotton or rayon piece goods are padded through a vat acid dispersion followed by drying. The material is then heat set (1–3 min. at 350° to 400°F) to fix color on the Dacron, followed by a passage through a continuous vat dyeing range to dye the rayon. Dyeings of good fastness have been obtained but the Dacron is lighter in shade. Other modifications of the Thermosol Process have been considered, but present problems in control of color migration in the required drying or heat setting operations. The concept of obtaining dye penetration by heat treatment should produce interesting results as the idea is pursued in future studies.

Dynel, Wool, Cotton, Rayon

Fiber blends of Dynel with wool, cotton, or rayon are developing increasing interest with emphasis on functional performance. Disperse dyes, the application of which comes under the theory of solid solution, are of particular interest for dyeing Dynel. A range of shades of mass-dyed Dynel has also been announced as available in the future. Since Dynel is blushed at its temperature of dyeing (205°–210°F) fabrics subjected to these dyeing conditions must be subsequently treated to restore the natural luster of the fiber. Blended Dynel fabrics are less sensitive to heat than 100% Dynel, hence the relustering operation may frequently be combined with an operation following dyeing, such as resin curing or semi-decating.

Blends of Dynel-wool of good fastness properties may be produced by stock-dyeing the individual fibers for subsequent blending. Disperse dyes are normally utilized for the Dynel, but combinations of disperse with neutral-dyeing premetallized or disperse with acid dyes applied by the cuprous-ion method may also be employed.

Good progress has been made in the dyeing of Dynel-wool piece goods. Selected neutral-dyeing premetallized acid colors have been found of interest for light to medium shades [1]. These are supplemented particularly for darker shades by the use of selected disperse dyes that stain wool little. A cationic dyeing assistant has proven of value for improving levelling and absorption of color by the Dynel. Dyeing of the disperse and premetallized acid dye is carried out as close to the boil as possible. Exhaustion of the disperse dye on the Dynel is assisted by a gradual addition of sodium sulfate. After dyeing, the dyebath is gradually cooled to avoid setting of wrinkles, and the material is well rinsed with warm water. The goods are then scoured at 160°F with a nonionic detergent to clean as much disperse dye as possible from the wool. Control of shade requires methods of sampling which will take into account the changes produced in soaping or relustering.

Satisfactory solid shades may be produced on unions of Dynel and rayon with selected direct and disperse dyes. The natural slight yellowish tint of the Dynel and the difficulty of bleaching limits the attainable brightness of certain pastel shades. In such cases, a balanced formulation will produce a somewhat duller union. Similar compensating factors may be necessary in order to improve fastness to light of such shades, which may be affected by a bleaching of the Dynel on exposure to light. In

general, fastness to actual sunlight is usually one unit better than Fade-O-Meter exposure would indicate.

Summation

I have endeavored to point out the extremely important part which coloration plays in the success of a new synthetic fiber. Limitations which may exist must be recognized by the textile technologist and stylist in planning a development. It may be necessary to limit the depth of shade on certain materials in order to avoid consumer complaints. An educational program at the consumer level may be required to make certain that dyed articles are properly handled. As an illustration, complaints were received on the wash fastness of a certain acrylic-wool blended knit dress-goods fabric. The stylist who had worn the same material reported no trouble with proper care in dry cleaning or washing. The public desire for easy living will promote cooperation in utilizing recommended methods for washing in lieu of the benefits of quick drying, resistance to wrinkling and shrinkage, and the minimizing of required ironing or pressing. Progress in dyeing the newer synthetic fibers has come from a careful screening of the known classes of dyes and the extension of these lines by dye research. Examples of this growth are the new disperse types, particularly in the anthraquinone series, new basic and acid dyes, and the expanding range of neutral-dyeing premetallized acid types. Research within these groups has been stimulated by application research and its correlation to dye structure. The importance of this factor was ably presented by the paper "Relationship Between Structure of Dyes and Their Dyeing Characteristics on Hydrophobic Fiber" presented by the Northern New England section of the A.A.T.C.C. at the Chicago Convention, September 19, 1953. Unfortunately, many of the dyestuffs which have the best fastness properties are difficult to apply to the hydrophobic fibers. No panacea appears in sight. It would appear that the newer methods of application will continue to be required and may have to be expanded. We can look to the future with confidence in the face of the continuing cooperation of the various sections of the industry and the support of the American public who are always interested in raising their standard of living.

Literature Cited

1. Anon., Union Dyeing Wool with Fibers Colored by Disperse Dyes, New York Section contest paper, presented before A.A.T.C.C. Convention, Sept. 19, 1953.
2. Blaker, R. H., Principles of Copper Dyeing of Polyacrylanitrile Fibers: The Controlled Redox—Potential Method, *Am. Dyestuff Reptr.* **42**, 76 (1953).
3. Cole, P. M., Barotor—Pressurized Fabric—Dyeing Machine, *Am. Dyestuff Reptr.* **42**, 32 (1953); Reth, J. E., and Andres, R. J., Dyeing Fabrics Under Pressure, *Am. Dyestuff Reptr.* **42**, 35 (1953).
4. Field, Jr., T. A., Latest Procedures for Dyeing Dynel, *Textile Age* **16**, 45–51 (1952) .
5. Field, Jr., T. A., Recent Developments in the Dyeing and Finishing of Dynel, *Am. Textile Reptr.* (Aug. 20, 1953).
6. Fortess, F., Sprague, B. S., and Stoll, R. G., Acetate Blends of Improved Performance (paper presented before A.A.T.C.C. Convention, Sept. 17, 1953).
7. Gibson, Jr., J. W., Knapp, P., and Andres, R. J., Thermosol Method of Dyeing, *Am. Dyestuff Reptr.* **42**, 1 (1953).
8. Iannarone, J. J., Clapham, H. F., and Thomas, R. J., Dyeing Wool at Elevated Temperatures, *Am. Dyestuff Reptr.* **42**, 666 (1953).
9. Meunier, P. L., Laucius, J. F., Brooks, J. A., and Thomas, R. J., New Developments in the Dyeing of Orlon Acrylic Fiber, *Am. Dyestuff Reptr.* **42**, 470 (1953).
10. Roy, A. P., New Developments in the Dyeing of Synthetic Fibers, *Am. Dyestuff Reptr.* **41**, 35–8 (1952).
11. Turner, C. F., Molten Metal Dyeing, *Am. Dyestuff Reptr.* **42**, 546 (1953).
12. U. S. Patent 2,627,449 (assigned to General Dyestuff Corporation) (Feb. 3, 1953).
13. Woodruff, J. A., Acrilan Acrylic Fiber Dyeing and Finishing, *Can. Textile J.* (May 23, 1952); Soday, F. J., Production and Properties of Acrilan, *Am. Dyestuff Reptr.* **42**, 635 (1953).
14. Zimmerman, C. L., Continuous Dyeing at Elevated Temperatures, *Am. Dyestuff Reptr.* **42**, 547 (1953).

Book Reviews

The Identification of Textile Fibers. Bruno Luniak. New York, The British Book Centre, Inc., 1953. 177 pages. Price, $10.00.

Translated from the Swiss text, thoroughly revised and up-to-date, and published as Communication No. 3 from the Swiss Federal Institute of Technology in Zurich, this is the most comprehensive work on the subject to appear thus far. Little information bearing on the subject has been omitted and all types of natural textile fibers, rayons, and synthetics are included.

An entire chapter is devoted to the microscope and its technique. Methods of sampling and sample preparation, methods of pretreatment, and determination of moisture content are treated in detail as are methods for both qualitative and quantitative analysis, chemical as well as physical. Numerous charts are included. A valuable addition is an atlas of 312 fiber photomicrographs prepared so as to permit direct comparison with observations on any standard microscope.

All in all, this book will meet not only the needs of the student but also serve as a complete reference for those actively working in the field.

Design Motifs of Ancient Mexico. Jorge Encisco, Compiler. New York, Dover Publications, Inc., 1953. 153 pages. Price, $3.95.

The 766 examples of ancient Mexican artistry, most of them taken from private collections and hence unavailable in other reference works, make this book unique as a source of ideas and ready-made designs for textile designers, artists, students, and hobbyists.

Much curiosity has been attracted by the small baked clay objects called stamps which were used in the ancient cultures of Mexico to decorate pottery and, after the conquest, applied also to the printing of trademarks and sometimes for purposes of identification. The forms illustrated are exact reproductions of the motifs and were made by stretching a thin sheet of paper over the stamp and retracing the surface with a pencil. The motifs cover a wide variety of forms and have been arranged in sections under Geometric Motifs, Natural Forms-Flora, Natural Forms-Fauna, The Human Body, and Artificial Forms. The illustrations are rendered in heavy black ink or good quality stock so that this can be used as a tracing book for stencilling and decoration.

No one can fail to be intrigued by the motifs which appear here in almost infinite variety and the book should serve a wide variety of interests.

Elementary Textiles. Julia Southard Lee. New York, Prentice-Hall, Inc., 1953. 437 pages. Price, $7.65.

As indicated by the title, *Elementary Textiles* is a textbook on textiles. It deals with fibers, yarn and fabric constructions, and finishes, and includes a chapter on textile standards and consumer problems. It will be of value to the student, to merchandising personnel, and to any one seeking information on (*a*) sources of textile raw materials, (*b*) properties which adapt fibers and fabrics to specific uses, and (*c*) the place of fibers in the economic life of people and nations. The book is well illustrated with photographs, charts, and tabular material and is documented with references to source material.

Generally the information is up to date but the reviewer has noticed a few exceptions. For example, Estron is given as "a generic term for filaments or staple fiber composed of one or more esters of cellulose." Actually Estron is the trade name for acetate staple and filaments made by the Tennessee Eastman Company. Also on page 398, colorfastness to atmospheric funes is A.S.T.M., D 682-52. A few changes in names of organizations have been made since the book was written.

All in all this is a most welcome addition to current reference works.

WANTED

TEXTILE CHEMIST

Outstanding opportunity for young Ph.D. with several years' experience in applied research on textiles, finishes, etc., and demonstrated supervisory ability to head established project sustained by prominent textile manufacturer in well-known research institution. Location Western Pennsylvania. Give full details including personal data, educational background and experience, salary expectations, first letter.

Address Reply To:

Textile Research Journal
10 East 40th Street
New York 16, N. Y.

Man-Made Fibers Handbook. Leonard Mauer and Harry Wechsler. New York, Modern Textiles Magazine, 1953. 52 pages. Price, $2.00.

First published serially in *Modern Textiles Magazine,* the text has been brought up-to-date, additional data and illustrations included, and is now made available as the *Man-Made Fibers Handbook.*

Of major importance is the section devoted to methods for the identification of fibers. In addition to a brief discussion of the subject, a chart covering all of the principal man-made fibers including X-51 shows the reaction of each fiber under eight different test methods.

Another section titled "Denier and Filament Numbers" deals with staple fibers, tow, and filament yarns. Manufacturers are listed and properties of the various types of their products as well as deniers are tabulated.

A concise description of properties and methods of manufacture, accompanied by flow charts, photographs, and fiber cross-section photomicrographs, occupies 43 pages.

Because of the large amount of up-to-date information arranged in form for ready reference, this handbook will be of value to all persons in any way connected with the textile industry or interested in informing themselves about the new raw materials which comprise the textiles they wear and use in their homes. It is already in use in textile courses and in employee training programs.

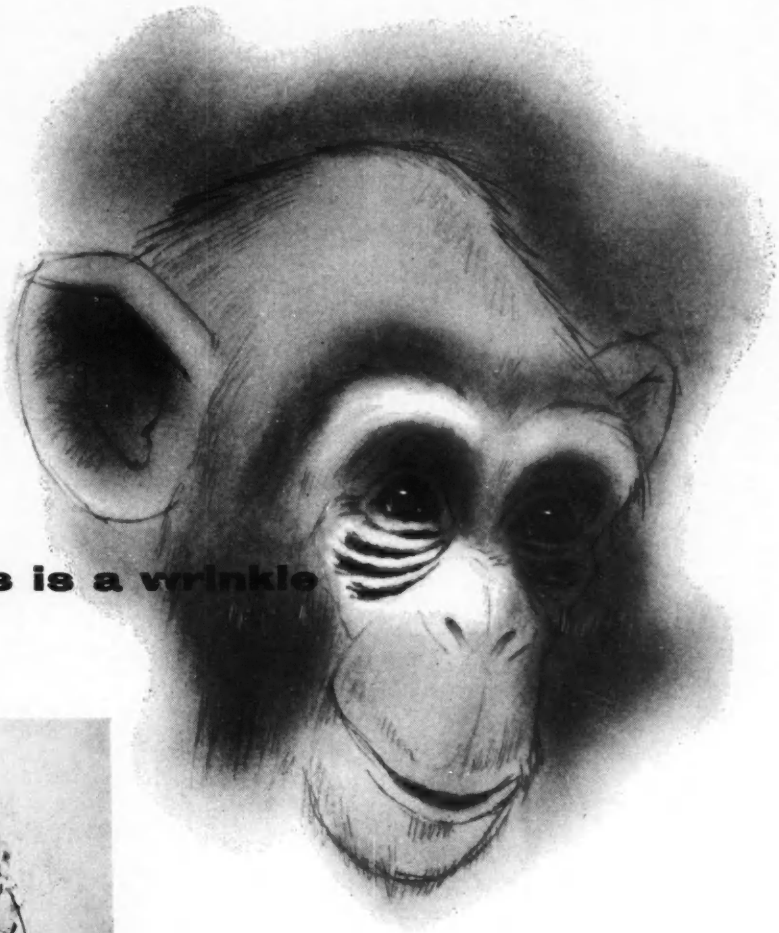
Review of Current Research and Directory of Member Institutions. Engineering College Research Council. State College, Pennsylvania, 1953. 330 + X pages. Price, $2.50.

This is the third biennial review published by the Engineering College Research Council, a unit of the American Society for Engineering Education. Current research in all branches of engineering and most related fields at 103 colleges and universities is reported. The institutions reporting are the current members of the Council and include all major engineering schools in the United States.

In addition to listing the project titles, information is given concerning the research policies of the reporting institutions, names of responsible administrative officers, number of research personnel, research expenditures, and, in some cases, sources and amount of research income. An index contains some 5,000 entries of research project subjects.

Although it has not been possible to differentiate between projects which are being vigorously pursued and those which are being carried on as an avocation for the intellectual satisfaction of the research worker, this *Review* furnishes a general picture of the research activities at the engineering schools of this country.

Copies may be ordered from V. E. Neilly, Secretary, Engineering College Research Council, 103 Mechanical Engineering Building, State College, Pennsylvania.



This is a wrinkle

A wrinkle has its "sometimes." Sometimes, on a monkey's face, for instance, it has a lot of charm. Sometimes, when it spoils the line of a skirt, the fit of a fabric, its nuisance value is considerable.

That's why Du Pont is proud to have contributed to the retirement of the wrinkle—through the scientific development of modern-living fibers. Nylon, Orlon, Dacron . . . each in its way contributes to textiles the strength and the value of wrinkle resistance. These modern-living fibers offer customers what they want today—wearable, packable clothes, worry-free, wrinkle-free pleats, men's wear, women's wear, and home furnishings of extraordinarily care-free wrinkle resistance.

And wrinkle control is only one of the many better values for better living that you can count on when you create fabrics made from Du Pont's modern-living fibers.

DU PONT'S MODERN-LIVING FIBERS

NYLON) RAYON) ACETATE) ORLON® ACRYLIC FIBER) DACRON® POLYESTER FIBER)

DU PONT

BETTER THINGS FOR BETTER LIVING . . . THROUGH CHEMISTRY

A WIDE VARIETY OF PRODUCTS *from* A WIDE VARIETY OF MATERIALS

REINFORCEMENTS
INSULATION
CLOTHING INTERLINING
UPHOLSTERY BACKING
FILTERS

SYNTHETICS -NATURAL FIBERS	SPECIAL MATERIALS	COARSE FIBERS
Acetate	Asbestos	Jute
Rayon	Rock Wool	Hair
Nylon	Glass	Sisal
Cotton		Reclaim Tire Cord
Wool		

Many new and unusual products are being developed

Because of the unique way the Rando-Feeder and Rando-Webber economically form a *Random Web* from almost any type of waste or staple fiber, many new products are now being developed . . . products unheard of a few years ago. Imagine making a web from hair, glass, asbestos or cocoanut fibers! All of these materials cannot be handled successfully on any other equipment.

Non-oriented webs have no crosswise, vertical or horizontal pattern . . . have strength in all directions . . . are resilient . . . will resist delamination and splitting. Webs made by Rando-Feeder and Rando-Webber can be dry processed, needle punched, quilted, felted and heat sealed.

Send us samples of your fibers. We will make webs for test purposes. Write for details.

RANDO-FEEDERS and RANDO-WEBBERS
AVAILABLE IN 3 SIZES
Now you can make Random Webs 40", 60" or 84" wide . . . up to 2" thick.

SEE OUR EXHIBIT AT ATLANTIC CITY APRIL 26 - 30 BOOTH 812-813

TEXTILE DIVISION
CURLATOR
CORPORATION
EAST ROCHESTER, NEW YORK